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Air Traffic Control Visual Scanning

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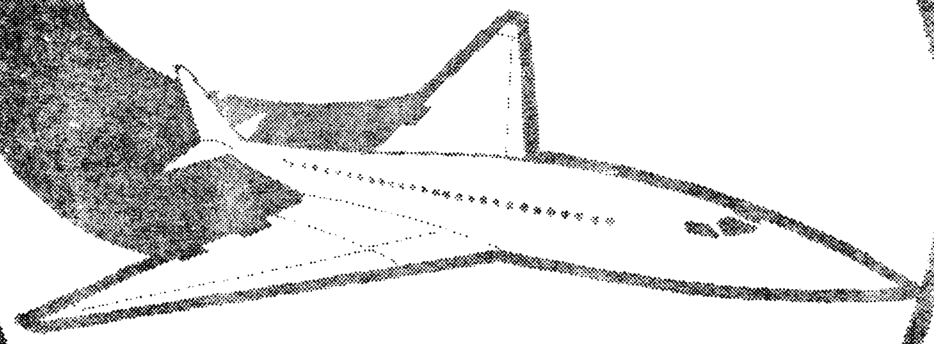

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16. Abstract

Air traffic controllers scan multiple displays to gather information necessary to make critical decisions in order to separate aircraft flying in the National Airspace System (NAS). When controllers make an error, they often respond that they did not see a piece of information that was right in front of them. Little is known about how controllers systematically scan their displays. This study was undertaken to determine whether there were patterns of scanning that characterized personnel with different levels of skill. Ten FAA controllers from a very active Terminal Radar Approach Control Facility (TRACON) participated in this study in which they controlled simulated radar traffic while their eye movements were monitored with an oculometer. This device allowed the computation of fixation frequencies and saccade duration during dynamic operations. Results indicated that the more experienced personnel had higher fixation frequencies than those who were in training. There were also significant changes in scanning behavior over time that the controllers worked. This occurred irrespective of experience and indicated that it takes between 5 and 10 minutes for the controller to establish a pattern which continues for the remainder of the work period. This suggests the importance of systematic relief period as personnel come on to control position.

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EXECUTIVE SUMMARY

Vision is the dominant information gathering sense. It is a complex resource about which there is still a great deal to learn. Human beings make mistakes, and these are often based on the assumption that they have seen all there is to see. They then make decisions which are not necessarily grounded on the best information available. In most daily activities, such errors are not hazardous and can be recovered. In the dynamic world of air traffic control (ATC), missing a piece of critical visual information can cause some serious consequences leading to an operational error. One of the most frequent comments made by controllers who have had an error is: "I didn't see it." The nagging question which follows such a situation is: "Why not"?

While every situation is specific, there may be common elements which relate to how controllers use their vision to search for information. This research was undertaken to learn more about controller visual scanning in a radar environment. The long term objective was to develop a better understanding of controller vision and, by doing so, help controllers avoid errors in the future. Previous research on controller scanning has been very limited and has focused primarily on what might be viewed as obvious. Radar controllers spend the majority of their time looking at the radar and proportionately less time at other sources such as flight progress strips. Prior work did not attempt to measure eye movements in a precise manner and relate them to controller performance. This was the goal of the current project.

There was no working definition of scanning when this program began. The following was developed to fill the void.

Scanning refers to a systematic and continuous effort to acquire all necessary visual information in order to build and maintain a complete awareness of activities and situations which may effect the controllers' area of responsibility.

During this project, ten current air traffic controllers participated in a simulation experiment which was based on the same airspace geometry as their home facility. This group included six full performance level (FPL) and four developmental controllers, all of whom volunteered to spend a week at the Federal Aviation Administration (FAA) Technical Center. They worked alternatively north and south final approaches to a simulated level V Terminal Radar Approach Control Facility (TRACON). During each simulation, everything that occurred in the airspace and every action by the controllers were measured and evaluated.

Eye movements were measured using an Applied Systems Laboratory oculometer. This employs an infrared light source which is mounted on a helmet worn by the participant. The system collects the light reflected from the right eye and computes the eye movements by measuring the relationship of the center of the pupil with respect to the center of the corneal reflection. In lay terms, this provides information on the number and duration of fixations along with the size of the movements between fixations known as saccades. During each day's activities, a person's eyes are constantly moving, and three to five fixations per second is common. The oculometer that was used is an older system and, unfortunately, it does not provide detailed information on the points of fixation or where the individual is actually looking. However, patterns of fixations can be plotted.

The research design called for the controllers to work in pairs, one used the oculometer and one who did not. This allowed for an evaluation of the impact of the oculometer itself. Other variables of interest were the differences in performance and scanning behavior between the two groups of controllers, FPL and developmental, and whether there would be any visual differences produced by two levels of work load.

When asked for their perceptions, controllers indicated that they found the occulometer annoying, but generally forgot about it when they were busy. Responses on a post-run questionnaire indicated that there were some differences of perceptions based on controller experience. Developmental controllers were more concerned about how tired they felt, while the FPL's felt there was a greater impact on their performance of metering of inbound aircraft.

Automated performance data were collected by the simulation itself. This was supported by an over the shoulder performance and workload rating accomplished by an air traffic controller serving as a member of the research team. Correlations between variables indicated that developmental controllers, overall, had slightly more between sector conflicts than did FPL's. However, this varied with the conditions under which they worked as will be shown below. The observer rated the performance of the FPL'S as superior to that of the developmentals. This may have been confounded since the observer knew who was who. However, he did his best to be objective. Other significant correlations included a positive relationship between task load and standard conflicts along with workload ratings. The more task load, the more standard conflicts there were, and higher workload was observed.

Analyses of variance were computed on the performance data and the observer ratings. They too showed a number of significant relationships. The frequency of standard conflicts increased

with task load, as indicated earlier by the correlation data. This was also true for the workload ratings. A measure of severity for between sector conflicts (BAPI) increased as a function of task load. These findings were irrespective of skill level. Two performance variables produced results that were complicated by the skill of the controllers involved. FPL controllers had fewer between sector conflicts when wearing the oculometer than when they were not. The developmentals, in contrast, had fewer when they were not wearing the equipment. This may well relate to levels of confidence and novelty of the situation. One might speculate that the FPL's were more careful when they wore the equipment and the developmentals were more anxious. There was also another relationship for a measure of conflict severity for between sector conflicts. When this was analyzed further, the only significant difference occurred between the FPL's and developmentals. When neither was using the oculometer, the FPL's had more severe conflicts. Again, this may relate to the level of confidence each group felt in the simulation environment.

Eye movement data were collected by the oculometer and consisted of different forms of two basic variables: fixations and saccades along with plots of this information. Correlations were computed between vision and performance variables. The number of keystrokes (PKEY) made by simulated pilots could be viewed as and indicator of controller activity level. PKEY was inversely related to saccade duration. The busier the controller became, the shorter and more frequent were his saccades. Also, saccade duration was inversely related to observer workload ratings. This meant that when the controller was receiving higher workload ratings, his saccades were of shorter duration.

Results indicated a multiple correlation of R= .857 when all vision variables were regressed on controller skill level. This was significant. Three vision variables made relevant contributions to this regression: fixation frequencies, saccade durations, and pupil means. The strongest of these variables and the one most easy to see in the table of vision data means was fixation frequency. FPL controllers had higher fixation frequencies than did the developmentals. They scanned the environment more and dwelled on individual points on the radar less. While this did not necessarily lead to better performance, it may mark a basic difference between more and less experienced controllers.

Vision data on selected variables were analyzed to determine if there was a time course to the scanning behavior of controllers. When 30-minute simulations were broken into six blocks of 5 minutes and analyzed, it was apparent that there were some significant changes over time. In the first 5 to 10 minutes both saccade magnitude and duration decreased, then stabilized for the remainder of the period. Fixation durations increased during the

first 5 minutes of the simulation, then stabilized for the remainder of the control period. These changes were irrespective of skill level or task load. It is well known that many errors occur during the beginning of a shift or right after a break. There are changes in visual scanning that are occurring during the same time period. Qualitative analyses of scan plots produced by the oculometer itself support the conclusion that it takes some time for the scan to stabilize and that for the situation described in the simulation, airspace geometry and traffic flow are major determiners of scan pattern. **These data suggest that the controller should be building his/her scan for a period of 5 minutes or so prior to taking actual control.**

At the conclusion of the vision and simulation portion of the project, each controller completed Cattell's 16 personality factor questionnaire (16 PF), which is a well known inventory of personality traits. This was done to see whether there were any differences between the two groups of participants. FPL's described themselves as more self-assured and imaginative than did the developmentals who indicated that they were more apprehensive. Relationships with other measures and personality were computed. Participants, primarily FPL's who were more concerned about the impact of metering on their performance indicated on the 16 PF that they were more calm, independent, and unpretentious. Overall, personality could be viewed as one of the resources that controllers bring with them to the work environment, and it likely has an impact on how they perceive their environment.

During exit interviews, controllers indicated that, on the whole, they were comfortable with the simulation and did not see any major impact of the oculometer itself. Almost all felt that their scanning methods were situation dependent. What they considered important included: traffic volume and flow aircraft speeds, weather, flow control, and critical points. Verbalized strategies agreed with what was seen on the scan plots. When asked about separation strategy preferences, the controllers confirmed previous studies in that other things being equal, they preferred vertical separation techniques.

INTRODUCTION

In the world of human perception, vision is generally accepted as the dominant means of gathering information. It is, however, infinitely more complex than many are willing to believe. Yet people, highly trained and competent professionals, make mistakes. They make judgments based on the belief that they have absorbed all there is to see, when there was data available right in front of them that they did not see. There is no dictum that quite covers this. If there was, it might read: "If you don't look at it, you can't see it."

In air traffic control (ATC), an operational error occurs when there is a loss of separation between two or more aircraft which resulted from something that the air traffic controller did or failed to do. Fortunately, the vast majority of these errors are technical violations of the rules for minimum separation but do not lead to catastrophic results. However, all errors must be taken very seriously, and controllers making them are encouraged to do better. During the period from September 1990 to August 1991 there were 749 operational errors recorded in the ATC work force (FAA, 1991). This represented a decline of 14 percent from the same period of the previous year.

No supervisor, leader, or researcher can judge what another human being sees or does not see. They can only infer based on what the individual says that he sees and what he subsequently does about it. In a highly complex person-machine system like ATC, defining and avoiding human error is a major concern. One of the most frequent statements made by personnel who have made a mistake is: "I didn't see it." In 1987, a Federal Aviation Administration (FAA) administrator's task force on controller error reduction identified two key areas of concern: memory lapses and visual scanning. In an effort to understand why and to subsequently reduce human errors in ATC, the FAA initiated a program in Controller Information Scanning.

PROGRAM BACKGROUND.

The ATC System has evolved over the years in response to user needs and available technology. Historically, the ATC process has been very human centered and dependent on the ability of air traffic controllers (Thomas, 1985). A great deal of what controllers do involves information acquisition and processing (Kirchner and Laurig, 1971; Sperundio, 1971). Everyone has limits in terms of the amount of information they can reasonably handle (Finkelman and Kirchner, 1980). With the technology of the 1980's, controllers must attend to a wide

range of detail. The future holds out the hope of machine assistance for the management of information. It remains unclear what the impact will be on human operators (Jenny and Ratner, 1974). Controller acquisition of knowledge and how it will be used are complex questions which bear further study (Spettell and Liebert, 1986; Warm and Dember, 1986).

Regardless of when or what promises technology holds for the future, the FAA still must deal with the present and the everyday potential for human error. Controller vision may be one area in which increased knowledge can help reduce operational errors.

"Man reveals many of his secrets in the pattern of his eye movements, a fact appreciated by oriental merchants, poets and policemen at least as long as it was by psychologists" (Alpern, 1971, p 369). Our ability to discriminate detail, often referred to as our visual acuity, drops off rapidly as light impinges further away from the eyes' point of clearest vision - the fovea. The eyes are practically in constant motion driven by six muscle groups which are among the fastest in the human body. We have the illusion of a stable visual field despite the constant eye movements and despite the fact that when the eyes are moving they are not taking in any information. Our impression of spatial solidity is created by our central nervous system, and the movement of the eye muscles is coordinated by a switching circuit in the brain stem. Actually, our eyes are not in constant motion. If that were true, we would be unlikely to see anything at all. Saccadic movement only occupies about ten percent of the total viewing time (Norton and Stark, 1971). The majority of time during our waking hours the eyes are stopped or fixated on objects and events in the surroundings. This is when they are acquiring information to reduce our level of uncertainty.

A literature review was conducted in 1989 to identify the amount and nature of whatever had been done on eye movement research in aviation (Stein, 1989). It was clear that considerable work had been accomplished in terms of so called vigilance studies, which generally involve basic signal detection paradigms. For example, Thackray, Touchstone, and Bailey (1978) reported studying the vigilance of men and women using a simulated radar task. However, they were studying detection latencies as a function of time on duty rather than measuring details of actual eye movements. The review also indicated that when researchers chose to evaluate eye movement data, there were many alternative ways of doing it, ranging in complexity from the informal observations of another human serving as observer to a variety of hi-tech systems, each of which had assets and limitations. Methods varied considerably in terms of the level of their intrusiveness on the operator.

It was apparent that while a good deal of research had been conducted in studying the behavior of pilots in the cockpit and in numerous laboratory vigilance studies, precious little had been accomplished in the ATC environment. There have been a few limited studies of controller eye movements. Wallis and Samuel (1961) used a technique called electro-oculography, which literally measures muscle movements around the eyes, but can generate little more than patterns of movement. Karston, Goldberg, Rood, and Sultzer (1975) evaluated the potential usefulness of an early oculometer to measure visual behavior. They were able to demonstrate what was conventional wisdom then and today. Controllers spend the majority of their time looking at the radar display and proportionately less time searching other data sources. Thackray and Touchstone (1980) used electro-oculography to evaluate the impact of radar sweep lines on scan patterns and David (1985) used a rather cumbersome video-based system to examine the impact of color on radar and other data displays.

What has become apparent is that while there is some literature on controller eye movements, it is very limited; and this is, in essence, an unexplored area which may well serve as a window into air traffic controller information processing. Virtually nothing is known about how controllers scan for information. Anything which is learned as a result of this study will add to the body of knowledge and eventually help the research community to assist controllers in doing their jobs more effectively.

A meeting was convened in June 1987 by Air Traffic Requirements (ATR) to discuss the nature of scanning and its impact on operations and training. It was noted that while automation had increased, the number of aircraft that a single controller could work had not increased appreciably, and controllers continued to make the same sort of mistakes. These were often attributed to a failure to perceive critical information. However, despite the ease with which people used the concept of "scanning" and the fact that whatever it was, it "has been done forever," no one had ever really defined scanning in an ATC context.

Definition: there is currently no one generally acceptable definition of the concept of scanning. It grew out of what appears to have been an attempt to develop an operational label for the problems seen in the applied ATC environment. The following is offered as a tentative working definition:

"Scanning refers to a systematic and continuous effort to acquire all necessary visual information in order to build and maintain a complete awareness of activities and situations which may affect the controllers area of responsibility."

This definition implies the ideal of a motivated operator who is reaching out for all necessary information and is managing the data flow efficiently. Anything which inhibits this process may well lead to an operational error.

METHOD

PARTICIPANTS.

Personnel involved as participants in this study were qualified ATC specialists from an operational Terminal Radar Approach Control Facility (TRACON) in a busy metropolitan area. They volunteered to come to the Technical Center for several days. All controllers were briefed concerning their rights to informed consent and anonymity. Participants were current in approach control procedures and had worked active traffic in the past 3 months. Controllers were selected from volunteer applicants based on their level of experience in ATC and whether they met basic criteria for study suitability.

Experience was supposed to be from two levels. Developmental controllers who have completed the radar school and have been on the boards for 1 year or less were originally specified as the journeyman sample. However, since we were recruiting from a very busy TRACON, what actually occurred was that the journeymen controllers were also fairly experienced, but were new to the facility and had to recertify after transferring from lower level operations at other TRACON's. The four developmental controllers had an average of 8.35 years in ATC (range 7.25 to 10.5) with only a mean facility experience of 1.1 years. The six Full Performance Level (FPL) controllers had an average of 10.68 years of experience (range 7 to 13.75) with a mean time in the facility of 4.25 years. The primary difference between the two groups was their experience in the facility in which they were now working. Everyone reported on their entrance questionnaire that their vision was good, they were in good general health, had freely volunteered to participate, and that they were motivated to participate. They were also asked to report on a 10-point scale the current level of stress in their lives. While there was no appreciable difference between the two groups (mean FPL 3.5 and mean developmental 4.5), there was a considerable range of responses from 1 (no stress) to 8 (signifying fairly high stress).

Participants had to be physically and mentally qualified to perform active ATC operations. Due to the relative shortage of full performance level controllers, participants volunteered on an as and where available basis. No pretext of systematic sampling is made. However, participants were selected by the TRACON from a pool of volunteers. The Technical Center requested that selections be made to cover

the normal range of performance abilities to help enhance generalizability.

QUALIFICATIONS.

This was a small sample study using available volunteers from one major urban tower/TRACON facility. While every effort was made to accomplish as much as is scientifically possible with the limited number of controllers available, any results should be viewed as indicative rather than conclusive. Subsequent decisions concerning changes should be done using all information available including expert judgement, possible replications of this study, and old fashioned common sense.

SIMULATION FACILITY.

This study was accomplished using the National Airspace System Simulation Support Facility (NSSF), which is an ATC simulator at the FAA Technical Center, Atlantic City International Airport, New Jersey. The NSSF is a general purpose ATC simulator designed to provide a realistic test bed for developing, testing, and evaluating advanced ATC concepts, airspace management plans, and procedures. The simulator consists of three subsystems: the Controller Laboratory, the Simulator Pilot Complex, and the Central Computer Facility.

The Controller Laboratory is a simulated en route or terminal control room, which includes eight radar displays and the associated keyboard entry and communication equipment. The laboratory is configured so that the participant controllers can function in a manner nearly identical to the way they do in the field. Controller-to-controller, controller-to-pilot (simulator operator), and pilot-to-controller communications are available and were used in this simulation. The controller portion or subsystem provides the sights and sounds of the ATC control room. While it is not a perfect copy of the radar room of an approach control (stimulus fidelity), it does provide fairly realistic opportunities for controller reactions to a variety of real world situations (response fidelity).

The second subsystem of the NSSF involves people who serve as the "pilots" of the aircraft under control. These Simpilots are in voice contact with the controller and respond to his directions. They fly their computer generated aircraft from a keyboard in an adjacent room. One Simpilot controls the flight of up to ten aircraft.

The final subsystem is the computer, which serves as both a target generator and as the collector of all systems information. This computer, a Gould SEL, samples the simulated airspace every second and records all aircraft

information to be described in more detail in a subsequent paragraph.

The operation of the simulation facility was the responsibility of the test director. He coordinated with the technicians, simulator operators, computer operators, and other personnel and organizations associated with the test effort.

The standard NSSF data reduction program was used to provide the following data elements (table 1):

TABLE 1. DATA MEASURES

LCNF..........	Longitudinal Conflicts
LAPI..........	Longitudinal API*
MLAPI.........	Median Longitudinal API
DLCNF.........	Duration Longitudinal Conflicts
SCNF..........	Standard Conflicts
SAPI..........	Standard Conflict API
SAPI..........	Median Standard API
BCNF..........	Between Sector Conflicts
BAPI..........	Between Sector API
MBAPI.........	Median Between Sector API
PKEY..........	Total Pilot Key Strikes
LAND..........	Arrival Landings

* To be defined later

TEMPORAL DATA.

The primary purpose of this effort was to evaluate the impact of the independent variables on the eye movements and performance of the participant controllers. Temporal data will consist of controller fixation frequencies and durations collected with the use of the Applied Systems Laboratory (ASL) oculometer. The concept of the oculometer and its operation are presented below.

EYE MOVEMENT DATA COLLECTION.

The system employs an infrared (IR) light source which is mounted on a helmet worn by the participant. The optical system collects the light reflected from the eye. A participant's eye movement with respect to the head and, subsequently, with respect to the point of fixation, is computed by the measurement of the center of the pupil and its relationship to the center of the corneal reflection. When the entire head moves, the center of the pupil and the center of corneal reflection move together. When the eyes move in the head, the relationship of the pupil and the corneal reflection changes proportionally based on the degree of eye movement.

Once the system is set up and the participant is in place, the operator of the oculometer manually acquires the center of pupil, the operator makes adjustments which set thresholds for the pupil discriminator and the corneal reflection discriminator so that the detections by the computer algorithms are reliable. The operator then performs a 9-point calibration of the individuals eye movements while he/she maintains head position. The optics or optical head coupled to the computer tracks the participants eyes, and the system allows limited head movement as long as the eye image remains centered in the field of view. The system is coupled with a video camera and monitor so that the operator can view the participant's eye along with the point of gaze superimposed as crosshairs on a video image of the screen.

The oculometer is quite typical of this level of eye measurement instruments. It records pupil diameter and works best when the pupil exceeds 3 millimeters. Its accuracy is approximately +/- 1 degree. It allows about 1 cubic foot of head movement. If the participant exceeds that, then pupil acquisition is lost and has to be reacquired. Loss of tracking can also occur by prolonged eye blink, coughing, sneezing, or anything which might mask the pupil or corneal reflection. One positive aspect of this particular system was that when tracking was lost, it most frequently reacquired the pupil on its own. The other manner of reacquisition would involve the technician doing the job manually with a joy stick controller. The system collects calibrated X and Y coordinates of fixation points on the stimulus scene at a sampling rate of 60 per second. The sampling rate is limited by the scan rate of the television equipment. While this system is not perfect, it does allow more flexibility and less obtrusiveness than those methods requiring complete head restrictions. It will collect fixation position and duration. The system can handle large amounts of digital data with minimal manual input.

RESEARCH DESIGN.

This experiment included three independent variables each of which had two levels. They were as follows: (1) controller experience, high and low, (2) system task load, high and low, and (3) use of oculometer, yes/no. The purpose of the third variable was to determine if the use of the oculometer itself had an impact on the controllers performance as measured by the data generated by the simulation itself. The overall design is depicted in figure 1. The design will employ repeated measures on the task load, oculometer variables, and independent measures on the subject variable of experience. Participants were randomly assigned to a preselected administrative order of those conditions on which repeated measures were collected. The administrative orders were used

Oculometer

Yes

Taskload

Skill	Low	High
Developmental		
FPL		

No

Taskload

Skill	Low	High
Developmental		
FPL		

FIGURE 1. RESEARCH DESIGN

to try and counterbalance the potential order effects of task load, high versus low, and the presence or absence of the oculometer. However, due to the final sample size, complete balancing was not possible.

PARTICIPANT ACTIVITY.

This study originally required 18 active controllers from an operating TRACON. All participants were volunteers who had freely agreed to travel to Atlantic City and work in the NSSF for approximately 3 days. All personnel came from the same operational facility which we simulated in the NSSF. This greatly reduced the time required to familiarize them with the simulation and increased the throughput of testing. In all cases, the participants were guaranteed both anonymity and confidentiality. No record of their individual performance was kept by name or other personal identifier.

PROCEDURE.

When the controllers arrived they were briefed on the background of the simulation effort: how the simulation will be conducted and what was expected of them. Essentially, the controllers were advised to function as they normally do. They were also advised that they would be given a questionnaire to be completed after every test run and that there would be a debriefing at the conclusion of their test participation. The purpose of the debriefing was to solicit feedback from the controllers on the overall simulation and any areas which could be improved.

The progression of a participant controller through the experiment is described graphically in figure 2. After an initial welcome and description of project goals to include an informed consent briefing, the controllers were asked to complete a brief questionnaire describing their background in ATC and current motivation for this project. Once entry processing was completed, a period of training and familiarization began so that results in the experiment would not be confounded by a learning curve as the controller tried to understand the simulator and the airspace as presented. This training was based on the Instructional Systems Design (ISD) model which called for the periodic evaluation of progress and for feedback of the results of that evaluation to both the trainee and to the training system. The evaluation was primarily based on expert judgement of in-house observer/evaluators. The training objectives included tasks, conditions, and standards as described the "Training-Familiarization Plan" which is attached as appendix A to this report. At the end of the first few hours of training, a decision point was reached as to whether or not the participant was ready or should have more training. The ten

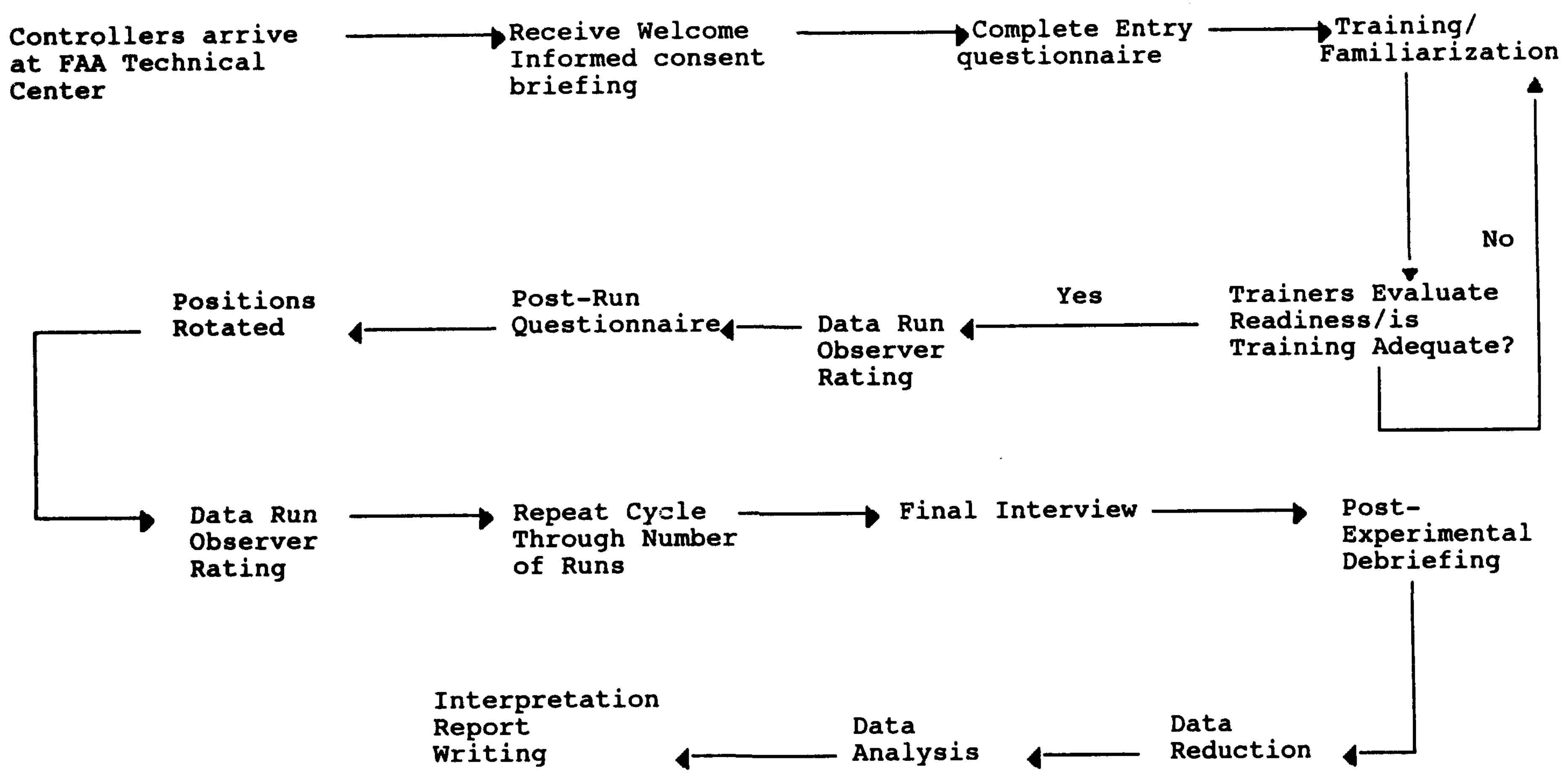

FIGURE 2. EXPERIMENTAL PROGRESSION

participants who came to the Technical Center all checked out on the simulation in the 2-hour block of training and familiarization, and no additional training was deemed necessary.

Prior to the beginning of data collection, each participant was assigned to one of the preselected administrative orders of the different combinations of the independent variables. All data collection was accomplished using an arbitrary letter code preassigned to each participant. No names were recorded on any forms and the list of names by codes maintained exclusively by the experimenter was destroyed at the conclusion of the experiment. This was to protect the privacy of the participants and to encourage their openness and honesty when completing questionnaires and interviews.

Each controller participant served in four simulation runs using an ATC environment that was based on his home facility. Two of these runs were at low task load and two were at high load. Controllers participated in pairs, and during each run one wore the oculometer and one did not. So each controller had one oculometer run at each task load.

A typical data collection run proceeded as follows: The experimenter informed the simulation manager prior to the run of the conditions under which the data will be collected. The simulation was set up accordingly. If the oculometer was to be used, the participant sat down and received the calibration procedure. Once this was completed, the participant received an airspace briefing from and air traffic controller familiar with the simulation and the airspace in use and was given a few minutes to evaluate and plan as he/she saw fit. The participant then took control of the airspace in the designated role. Each data run was 1/2 hour and involved free play simulation in which the participants made all the decisions normally made by an individual in his position. Data collection occurred both during and after each simulation run. During the run, it consisted of both manual and automated methods. The manual system was based on the continuous observation of an observer/evaluator who made entries every 15 minutes on an evaluation form, a copy of which can be found in appendix B. The automated system involved the continuous sampling by the simulation itself of systems variables (see table 1 for a sampling of these) which include aircraft status, changes in status, separation between aircraft pairs, and participant controller actions. The simulation system can provide these data in raw form or with a considerable amount of processing to include cumulation over time intervals. The oculometer subsystem served as an additional automated data collector sampling eye movements at a rate of 60 frames per second and recording the data in the ASL format. After each data run, the participant was asked to

complete a questionnaire (shown in appendix B) designed to gauge their assessment of how hard they had to work on that run and how they felt that they performed. They were also asked for whatever strategies that they established for the run and for their subjective impressions of the impact of the oculometer if applicable for that run.

At the conclusion of all the data runs, each controller participant was given an exit interview (see appendix B) and asked to complete a personality inventory called the "Sixteen Personality Factor Questionnaire" (Cattell, Eber, and Tatsuoka, 1970). This instrument is used as part of the entrance testing for new air traffic controllers, and was employed to determine whether there would be any differences between the two small groups of controllers who participated based on their status as developmentals or FPLs.

RESULTS

CONTROLLER QUESTIONNAIRE.

At the end of each 1/2 hour of simulation, controllers were asked to complete a questionnaire which basically described their experience in the simulation. They were asked to evaluate their workload, self-assess their performance, and provide information on the following scales: stress, level of interference by the oculometer, traffic volume and composition, impact of runway layout and aircraft at the edges of the display, metering of in-bound aircraft, and personal fatigue. The mean participant responses to these questions are presented in table 2.

A visual inspection of this table indicates the possibility that participants found the presence of the oculometer annoying. Controllers reported a moderate degree of interference from the oculometer. This was not at all surprising given the weight of the helmet and the restrictions that it engendered. It was also apparent that FPL controllers were more confident of their level of performance with and without the oculometer than were the developmentals. No one indicated that the experience overall was particularly stressful, especially after they adapted to the presence of the oculometer and the simulation itself. The developmentals appeared to be more bothered by the necessity of monitoring aircraft at the edges of the display which is where the possibility of incursions may be greatest. However, no incursions were planned as part of this study.

TABLE 2. MEAN POST RUN PARTICIPANT RESPONSES

Question	Respondent FPL(1) Oculometer Yes	No	Developmental(2) Oculometer Yes	No
Workload	5.50	4.50	5.00	3.88
Performance	8.33	7.75	6.25	6.88
Time Busy	5.83	5.25	5.88	5.00
Stress	4.08	3.42	4.88	3.00
Interference	5.25	1.75	4.25	1.50
Traffic Volume	6.67	5.92	6.25	6.13
Traffic Composition	5.83	2.93	7.00	5.92
Runway Layout	2.50	2.25	3.88	2.63
Aircraft at Edges	3.42	3.42	5.13	4.63
Metering	4.42	4.83	4.13	4.00
Fatigue	2.42	1.58	3.63	2.13

These data were initially analyzed by intercorrelating all the scales to include the additional variable of the presence or absence of the oculometer. Results indicated that participants did find that the presence of the oculometer was annoying. The interference question correlated r=.59(P<.001) with the presence or absence of the oculometer. Controllers responded in post-run interviews that they were most aware of the helmet mounted equipment when their task load was low and tended to forget about it when busy. They also indicated in their questionnaire that their level of stress, r=.68(P<.001), was directly related to their workload and the percentage of time they were kept busy, r=.62(P<.001). Surprisingly, controller responses on workload were independent of their self-assessment of performance, r=-.03. We often find in this type of research at least a mild inverse relationship, but these participants did not see it that way.

Linear regression analyses were computed using all the questionnaire variables against two independent variables: the presence or absence of the oculometer and the skill level of the participants (which was coded as "1" for full performance controllers and "2" for developmental or trainee controllers). The purpose of this analysis was to determine the degree to which the questionnaire itself could identify whether the oculometer was in use (did it impact participants' perceptions) and the impact of controller skill on questionnaire responses. Results on the presence or absence of the oculometer provided a multiple R of .697. An analysis of variance (ANOVA) on the regression was computed and was significant (F=2.41 P<.05). (The concept of ANOVA will be explained in the Automated Performance Data section later in this report.) This meant that the relationship did not occur

by chance. The one variable that had the greatest impact on the regression was, not surprisingly, the question on the level of interference of the oculometer.

A second linear regression computed on skill as an independent variable provided a multiple R of .73 with a significant ANOVA on the regression ($F=2.94$, $P<.05$). A number of questionnaire items made a significant contribution to this regression. The reader will recall that fully trained controllers were coded as "1" and trainees were coded as "2". So responses that have positive correlations with the regression indicate that trainees tend to rate them higher and those with an inverse or negative loading indicate that FPL controllers rate them higher. The following is a listing of significant beta weights which reflect the contribution of the respective variables to the regression equation (table 3).

TABLE 3. BETA WEIGHTS ON THE IMPACT OF SKILL ON QUESTIONNAIRE RESPONSES

Metering	-.61
Interference	-.44
Fatigue	.43
Aircraft on Edges	.54

This table indicates that the controllers answered some questions differently based on their experience. FPL controllers were more concerned with the impact of the metering of in-bound aircraft and the annoyance produced by the oculometer. The developmental controllers saw their fatigue and the impact of having to monitor aircraft at the edges of the display as the more important elements of their experience.

As it turned out, judging from the analysis of actual performance to be discussed in Automated Performance Data section, this was a classic case of perceptions diverging from reality. However, despite what controllers thought, when their actual performance was regressed against the presence or absence of the oculometer, the multilinear regression provided a multiple $R=.37$, which was not significant. The analysis of variance on the regression was only $F=.41$ ($P>.05$).

At the end of the questions that required numerical answers, controllers were asked to describe their strategies for working the traffic in the simulation. In all the responses provided, no one cited the oculometer as an influence in their operational strategy one way or the other. The majority of the comments seemed to focus on the maintenance of horizontal separation using very traditional techniques of speed control and vectors. The amount of detail and complexity of the operating strategies varied considerably ranging from just a

few words, i.e. "have the aircraft at compatible speeds," to multistep procedures such as: "ensure I had vertical separation with the base leg and downwind traffic. Also make sure the south final aircraft were below my altitude." The more complicated strategies appear to have been characteristic of the more experienced controllers.

Another question asked participants if there was anything which had occurred which might have influenced the results. There were a number of comments which related to the operation of the simulation itself. For example, there was no automatic offset on the data tags that the participants had available in their home facility. Pilot errors occurred and they had to take corrective action. While this was not a planned element of the experiment, simulation pilots do make errors, and, for that matter, so do real pilots. One controller complained that the helmet hurt his head after he wore it awhile. Another noticed a reduction in peripheral vision while wearing the helmet. Neither of these issues was cited more than once.

AUTOMATED PERFORMANCE DATA.

In addition to the perceptions collected from the controller participants by questionnaire, this type of research is very data rich in terms of the availability of both performance indicators and visual scanning data. Part of the challenge of vision research in an ATC simulation environment is deciding what to analyze for the current purpose and what to set aside for later.

The simulator itself generates variables on virtually everything that is going on in the "airspace." Every time two aircraft come too close together, the information is duly recorded. This can happen in number of different ways. While the number of variables that can be produced by processing the flight data of the simulated aircraft is limited primarily by ingenuity and computer time, there is a good deal of redundancy in these measures. A limited subset was selected from those available based on experience with the simulation. The following table 4 is a repeat of this list which was also presented earlier (table 1) in the report in the design section.

In addition to these so called hard data variables, there was input from the over-the-shoulder observer, who rated the performance (PERFRT) and workload (WLRT) of controllers using the oculometer on any given run. It was decided to integrate these rating data into the analyses since they provided input from a professional controller serving as observer and had considerable face validity.

TABLE 4. AUTOMATED PERFORMANCE MEASURES

LCNF........ Longitudinal Conflicts
LAPI.........Longitudinal API*
MLAPI........Median Longitudinal API
DLCNF........Duration Longitudinal Conflicts
SCNF.........Standard Conflicts
SAPI.........Standard Conflict API
SAPI.........Median Standard API
BCNF.........Between Sector Conflicts
BAPI.........Between Sector API
MBAPI...... Median Between Sector API
PKEY.........Total Pilot Key Strikes
LAND.........Arrival Landings
* API is a measure of Conflict Severity

The first step in the analysis of these data was to intercorrelate all the performance variables to include those generated by the observer. Pearson product-moment correlations were computed. These evaluate the degree to which two variables covary in relationship to the amount of variance within each. If, for example, variables A and B are perfectly correlated, the result will be a correlation coefficient of r=1 or r=-1 meaning that they each have little internal variability in comparison to how they vary together (i.e., as "A" increases "B" increases at the same pace).

The results of these correlations are presented below in table 5.

TABLE 5. INTERCORRELATIONS OF PERFORMANCE VARIABLES

	LCNF	LAPI	MLAPI	SCNF	SAPI	MSAPI	BCNF	BAPI	MBAPI	PKEY	LAND	WLRT	PERFRT
Skill	.29	.29	.23	-.11	.01	.28	.67	.25	.30	-.08	.32	.32	-.54
TASKLOAD	.23	.21	.14	.45	.11	-.20	-.27	-.41	-.16	.41	-.29	.48	-.04
LCNF		.99	.75	.38	.01	-.02	.18	-.04	.07	.45	.09	.44	-.34
LAPI			.85	.39	.00	-.03	.18	-.05	.06	.43	.10	.43	-.35
MLAPI				.35	-.04	-.06	.15	-.07	.01	.29	.12	.33	-.31
SCNF					.45	.25	-.22	-.19	-.05	.74	-.06	.47	-.23
SAPI						.59	-.01	-.00	.02	.13	-.39	.36	-.18
MSAPI							.14	.32	.34	.26	.03	.38	-.46
BCNF								.33	.28	-.44	.31	-.01	-.58
BAPI									.85	-.18	.32	-.03	-.23
MBAPI										-.01	.14	.07	-.46
PKEY											.15	.50	-.06
LAND												-.29	.06
													-.49

These correlations were based on only those runs in which observer data were available and would produce a complete matrix. The observer only rated the oculometer position.

There were no observer ratings on the other position. Every participant was rated on each level of taskload. However, the correlations were also computed for all runs and participants and did not differ appreciably for the intercorrelations of the performance variables without the observer input.

Like most statistical techniques, one question that is usually asked about correlation is whether or not it could have occurred by chance given the conditions and the participants that were involved. With the above table, the criterion for whether a given relationship may have existed beyond a chance probability is determined by the size of the correlation and the number of degrees of freedom involved in computing the correlation, in this case 18. The correlation would have to exceed r-.44 in order to conclude that it probably did not occur by chance.

The intercorrelations of performance variables provided two kinds of information. First, it provides an estimate of variables that are redundant. If two variables correlate highly, then they are basically telling us the same thing. For example, LCNF, the number of longitudinal conflicts, correlated r=.99 with its complementary score LAPI, which is the aircraft proximity index computed on the same conflicts. Besides giving the investigator a handle on redundant variables, it provides first look at relationships with key variables such as taskload and skill.

Examining the top line of the *correlation matrix*, we see the computed values for skill level against performance indicators and observer ratings. There is a significant positive relationship r=.67 between BCNF, the between sector conflicts, and skill. This is positive, because it will be recalled that the developmental controllers were arbitrarily coded as 2's and the FPL's were 1's. Developmental controllers had more between sector conflicts in the simulation. There was also an inverse correlation r=.54 between skill and the observers performance rating. This meant that the observer tended to rate the performance of the FPL's higher than the developmentals. This may have been a self-fulfilling prophesy, however, because the observer was not working blind and knew who was who in the experiment. The second horizontal line in the matrix was also informative. There were two significant correlations. Taskload correlated significantly r=.45 against SCNF, the number of standard conflicts, and r=.48 against the workload rating. It should be noted that these correlations, while they indicate a positive relationship they do not demonstrate a strong relationship and, therefore, are only indicators that something may be going on.

Table 6 summarizes the mean or average scores for each of the performance variables and observer ratings. The reader will note that different scales apply and that comparisons within a given dependent variable across the experimental conditions described at the left of the table are reasonable, but attempting to compare across variables is not.

Reading this complex table is a challenge at the best of times and trying to find meaning is even more difficult without a guide. The procedure that was used to evaluate whether or not there was meaningful variance underlying the table were two very basic statistical techniques called analysis of variance (ANOVA) and analysis of co-variance (ANCOVA), respectively. What they both do is determine the probabilities that the observed differences between the means generated by the different experimental conditions could have occurred by chance. When differences are determined to be significant, it is interpreted to mean that it is unlikely, but not impossible, that they occurred by chance alone.

TABLE 6. PERFORMANCE DATA MEANS

Experimental Condition		LCNF	LAPI	MLAPI	SCNF	SAPI	MSAPI	BCNF	BAPI	MBAPI	PKEY	LAND	WLRT	PFRT
FPL'S														
Task	Oculometer													
Low	No	0.43	0.86	0.71	1.57	6.29	6.14	3.14	14.57	8.14	1141.86	9.86	----	----
High	No	1.00	0.50	0.50	2.33	2.83	1.00	3.00	8.67	7.50	1418.83	9.83	----	----
Low	Yes	0.00	0.00	0.00	0.83	1.67	1.67	2.50	11.50	4.67	1146.33	9.67	5.75	9.50
High	Yes	0.17	0.17	0.17	2.83	4.67	1.17	1.17	4.33	4.33	1420.67	9.00	7.00	9.50
All FPLS		0.40	0.40	0.36	1.88	3.96	2.64	2.48	9.96	6.24	1276.32	9.6	6.38	9.50
Developmentals														
Task	Oculometer													
Low	No	1.00	1.67	0.33	1.33	2.33	1.67	3.33	14.00	3.67	1126.00	10.33	----	----
High	No	1.25	5.50	0.50	5.50	7.50	0.75	1.25	1.25	1.25	1339.00	9.50	----	----
Low	Yes	0.25	0.25	0.25	1.25	4.00	4.00	4.25	18.75	10.00	1155.00	10.50	6.63	8.38
High	Yes	1.25	0.75	0.25	1.75	2.50	2.00	4.00	7.75	6.00	1322.25	9.75	7.75	8.13
All Devs		0.93	2.07	0.33	2.53	4.20	2.13	3.20	10.20	5.33	1242.87	10.00	7.19	8.25
All Personnel		0.60	1.03	0.35	2.13	4.05	2.45	2.75	10.05	5.90	1263.78	9.75	6.70	9.00

The first step in the process used to analyze the performance data was to compute a three-way ANOVA on each of the dependent variables. It was initially a three-way analysis because of three independent variables: skill level, taskload, and oculometer presence or absence. Table 7 lists the results of these analyses by dependent variable.

TABLE 7. THREE-WAY ANOVA'S OF PERFORMANCE VARIABLES

Variable	Main Effects	Interactions
LCNF	None	None
LAPI	None	None
MLAPI	None	None
SCNF	Taskload*	None
SAPI	None	None
MSAPI	None	None
BCNF	None	Skill by Oculometer*
BAPI	Taskload*	None
MBAPI	None	Skill by Oculometer*
PKEY	Taskload*	None
LAND	None	None
WLRT	Taskload*	None
PFRT	Skill*	None

* P<.05

This table shows several facts. A main effect is the result of one of the independent variables. While it is possible to obtain a significant main effect in a design that also has an interaction, it is not possible to determine what it means without breaking down the interaction. On the performance variables in this study there were no significant main effects in variables that had an interaction. An interaction indicates that the results of the independent variables, as seen in the measurement of the dependent variable, were not directly additive. For example, on the surface it appears that for BCNF, there were no main effects from taskload, skill, or oculometer presence. However, the interaction indicates that in order to interpret the impact of skill, for example, you must evaluate results with and without the oculometer separately.

In order to understand the results in table 7, the reader is encouraged to also examine table 6, Performance Data Means. The following is the interpretation of each of the variables, in turn, which had either main effects or interactions. SCNF is the first variable to show significance. Results indicate that there were more standard conflicts at the higher taskload regardless of whether the oculometer was in use or what the skill of the controller was working the airspace. For BCNF, it was more complicated because there was a skill by oculometer interaction ($F=10.09$, $P<.01$). This was handled first by simplifying the situation, then by running an analysis of covariance and removing any contribution contributed by taskload. In table 8 are the adjusted means

for the contributions of skill and oculometer on BCNF between sector conflicts.

TABLE 8. ADJUSTED MEANS FOR BCNF

Skill	Oculometer Yes	Oculometer No
FPL	1.83	3.04
Developmental	4.12	2.20

In order to evaluate where significant differences actually exist between the cells of this design, post-hoc comparisons had to be made. Since each of these comparisons involved only two levels, it was simplest, given the computer tools available, to go directly to a technique called the Newman-Keuls analysis, which makes these comparisons allowing for the number of levels involved. The following represents the results for the specific comparisons on BCNF (table 9).

TABLE 9. SPECIFIC COMPARISONS FOR BCNF DATA

Variable	Significant?
Skill - No Oculometer	NS
Skill - Yes Oculometer	*
Oculometer - FPL's	*
Oculometer - Developmentals	*

* P < .05, NS= Not Significant

The only combination that was not significant was the impact of skill when there was no oculometer in use. When using the oculometer, developmental controllers made significantly more errors than did the FPL's. Ironically, the FPL's made more errors without the oculometer than with it. One might speculate that the annoyance they reported from the equipment encouraged them to pay more attention to the airspace between the sectors.

The next performance variable which showed significance was BAPI. This was the aircraft proximity index computed for the between sector conflicts. Only taskload was significant ($F= 7.46$, $P< .01$). Referring back to the table of means, the results of BAPI are very interesting when evaluated in terms of taskload. Regardless of skill or oculometer presence, when taskload increased, the severity of between sector conflicts, as measured by BAPI, decreased. Again, higher taskload may have lead to greater vigilance.

The next variable to reach significance was MBAPI. This was the median between sector API scores instead of using means as in BAPI. The three way ANOVA produced a skill by oculometer interaction ($F=5.43$, $P<.05$). As with the previous situation with the BCNF variable, it was decided to simplify the

situation by computing an ANCOVA and removing any variance that might have been contributed by the taskload. The ANCOVA also produced a significant skill by oculometer interaction ($F=5.89$, $P<.05$). The adjusted means for the remaining design are listed below in table 10.

TABLE 10. ADJUSTED MEANS FOR MBAPI

	Oculometer	
	Yes	No
Skill		
FPL	4.50	7.78
Developmental	8.00	2.40

While it would appear that there are considerable differences here based on skill and the presence of the oculometer or its absence, post-hoc testing using the Newman-Keuls procedure does not bear this out. It only takes one difference to drive the interaction. Table 11 presents the results of the post-hoc analysis.

TABLE 11. POST-HOC ANALYSIS OF MBAPI

Variable	Significant?
Skill - No Oculometer	*
Skill - Yes Oculometer	NS
Oculometer - FPL's	NS
Oculometer - Developmentals	NS

*P< .05 NS=Not *Significant*

Without the oculometer, FPL's had more severe between sector conflicts than did the developmental controllers. Were they overconfident? One might speculate that the developmentals attempted to create larger buffers between aircraft due to their lack of experience in the airspace; so when they had a conflict, it was less severe as measured by the median between sector API scores.

Why were the other possible paired comparisons in table 11 not significant? There are a number of statistical issues. First, the Newman-Keuls technique is fairly conservative and attempts to control the probability that significance will be found where none exists. It computes a critical difference necessary for each comparison that it makes taking into consideration the internal variability of each cell in the design and the degrees of freedom, which are determined in part by sample size. Since the number of developmental controllers was less than the number of FPL's, there was less statistical power available for the comparison of developmentals across the oculometer variable. Judging from the table of means alone, it appears that it should have been significant. By using a less conservative test, such as the

"t" test, significance could have been achieved for the developmentals across the levels of oculometer. This would have been an attempt to pursue something that may well not exist, and it was not reported here.

The last three-way ANOVA to demonstrate any significance was the analysis on PKEY, the frequency of pilot keystrokes in response to controller inputs via the simulated radio channel. PKEY is an effective indicator of how active the controllers are on the radio. In the current design, only one main effect was significant and this was taskload ($F=7.67$, $P<.01$). Referring back to table 6, the reader can see quite clearly that it did not matter who the controllers were or whether or not they were using the oculometer. Higher taskload, which was part of the research design, led to higher frequencies of keystrokes by the pilots and, undoubtedly, a higher frequency of radio instructions from the controller to the simulation pilots.

The last performance data analyses were conducted on the observer's ratings. Since he only rated the oculometer position, the design for this analysis involved only two factors: taskload and skill. Two-way ANOVA's were computed for the performance (PFRT) and the workload (WLRT) ratings, respectivey. As indicated earlier in table 11, both of these analyses resulted in one significant main effect each. For WLRT, the significant main effect was taskload ($F=5.33$, $P<.05$). Higher task loads were viewed by the observer as producing higher workloads. Since this was not a blind rating, however, the observer knew which runs were operated at each of the two levels of taskload, so his ratings may have been somewhat confounded. For PFRT, no other independent variables influenced the results other than the skill level of the participant. FPL's were invariably rated higher than were the developmentals ($F=6.71$, $P<.05$). This too could have been confounded because the observer knew who was who. The observer was a professional and doubtlessly tried to maintain his objectivity to the extent humanly possible.

EYE MOVEMENT DATA.

There were two basic vision variables with a number of ways of looking at each. These were saccades or movements between fixations and the fixations themselves. Fixations have frequency and duration, and saccades have frequency and magnitude. An additional variable called eye motion workload was created by an engineer, George Hetrich, at the FAA Technical center. It was computed by taking the average saccade motion in degrees and dividing by the number of saccades. The larger the number, the more the eyes moved on the average between fixations. The oculometer generated basic data concerning the saccades and fixations. Then, through

statistical processing, additional variables were created against the possibility that each would add something to the knowledge of the scanning process. What follows are the definitions of the variables that will be seen abbreviated in subsequent analyses (table 12).

TABLE 12. DEFINITIONS OF VISION VARIABLES

FIXMEAN	Average Fixation Duration (Seconds)
FIXMDN	Median Fixation Duration (Seconds)
SACDURM	Average Saccade Duration (Seconds)
SACDURMD	Median Saccade Duration (Seconds)
SACMAGMN	Average Saccade Magnitude (Degrees of Angle)
SACMDN	Median Saccade Magnitude (Degrees of Angle)
PUPIL MEAN	Average Pupil Size (ASL Units)
PUPIL MDN	Median Pupil Size (ASL Units)
FIXFREQ	Average Fixation Frequency (Count)
VISEFFIC	Visual Efficiency
EYEMOTWL	Eye Motion Workload
PUPILMOTWL	Pupil Motion Workload

The last three variables in table 12 were developed by George Hetrich who was doing some of the data reduction analyses at the FAA Technical Center. Visual efficiency is the proportion of the total scanning time that is spent fixating. It is computed using the following formula: Average Fixation Duration * Fixation Frequency/(Average Fixation Time * Fixation Frequency) + (Average Saccade Duration * Saccade Frequency). This provides a fraction from 0 to 1. Eye motion workload is the average degrees per second that the eyes moved during the entire scanning period. This is computed by the formula: Average Saccade Magnitude * Saccade Frequency/Total Time in seconds. This provides a number in degrees per second for each 1/2 hour simulation. The last Hetrich measure was pupil motion workload. This refers to the change in pupil diameter over time. Pupil diameter was measured at each fixation. Pupil motion workload was computed by cumulating the absolute value of the differences between each pair of fixation records. These pupil diameter values were then averaged for the total run by dividing by the total time in the simulation. The result was in ASL units, an arbitrary metric developed by the manufacturer of the oculometer. This was then converted to units of millimeters per second by applying a conversion formula using .044 millimeters per ASL unit, which was the ratio provided by the manufacturer.

A summary of all the vision related data to include variables which are derivations of the more basic saccades and fixations is presented in table 13.

TABLE 13. VISUAL DATA MEANS

Experimental Condition	Vision Variables											
	FIX MEAN	FIX MDN	SAC DME	SAC DMD	SAC MGME	SAC MGMD	PUPIL MEAN	PUPIL MDN	FIX ATF	VIS EFFI	EYE MOTION	PUPIL MOTION
FPL's												
Task												
Low	0.42	0.31	0.11	0.03	5.23	2.70	126.83	127.83	3780.33	0.80	10.28	3.05
High	0.47	0.36	0.09	0.03	5.92	3.23	129.33	131.00	3567.00	0.84	10.87	2.30
All FPL's	0.41	0.33	0.10	0.03	5.57	2.96	128.08	129.42	3673.66	0.82	10.57	2.67
Developmentals												
Task												
Low	0.44	0.33	0.12	0.03	5.85	3.18	125.00	126.75	3456.75	0.78	10.61	5.58
High	0.53	0.39	0.12	0.02	5.34	3.00	119.25	122.00	3085.50	0.80	9.11	1.91
All Devs	0.48	0.36	0.12	0.02	5.59	3.09	122.13	124.38	3271.13	0.79	9.86	3.75
All	0.44	0.34	0.11	0.03	5.58	3.02	125.70	127.40	3512.65	0.81	10.29	3.10

The diversity of units of measurement is obvious from this table. Also, a cursory glance within the different variables and across task loads and skill levels are not very informative. There appears that there might be a difference in fixation frequencies between the FPL's and the developmentals, but not much more information is available just from looking at the table itself.

The next step in the analysis was to search for redundancy among the vision variables. Since some were the product of the same sources and were simply different ways of looking at the same information, it seemed likely that they would be closely related. This was accomplished by intercorrelating all the vision variables. Table 14 provides the Pearson product-moment correlations of the vision variables along with their relationships to the observer's ratings of WLRT and PFRT. As in the previous tables, any correlation above the absolute value of .44 is significant from zero. This does not necessarily mean that a correlation of .44 accounts for a great deal of common variance, only that it probably did not occur by chance. In terms of redundancy, there were a number of strong relationships such as the one between FIXMEAN and FIXMDN and between PUPILMEAN and PUPILMDN. Relationships like these with correlations of r=.99 and r=1.0, respectively, indicate that the variables involved are, for most purposes, virtually interchangeable.

TABLE 14. INTERCORRELATIONS OF VISION VARIABLES

	PFRT	FIX MEAN	FIX MDN	SAC DURM	SACD URMD	SAC MAGMN	SAC MDN	PUPIL MEAN	PUPIL MDN	FIX FREQ	VISE FFIC	EYE MOTWL	PUPIL MOTWL
WLRT	-.49	.14	.14	-.47	-.59	.11	.16	-.16	-.15	.10	.41	.15	-.15
PFRT		.41	.42	-.16	.18	-.12	.04	.18	.18	-.37	.31	-.47	-.21
FIXMEAN			.99	-.20	-.41	.28	.59	.59	.63	-.87	.58	-.62	-.01
FIXMDN				-.23	-.43	.25	.57	.55	.58	-.86	.61	-.63	-.04
SACDURM					.75	.05	-.09	.06	.06	-.25	-.90	-.11	.08
SCADURMD						-.23	-.38	-.20	-.21	.01	-.79	-.12	.03
SACMAGMN							.91	.73	.71	-.37	.06	.46	.02
SACMDN								.81	.81	-.59	.32	.14	.07
PUPILMEAN									1.00	-.62	.20	-.01	.19
PUPILMDN										-.65	.22	-.05	.19
FIXFREQ											-.17	.64	-.00
VISEFFIC												-.19	-.02
EYEMOTWL													-.04

Due to the results of the intercorrelations of the vision data, it was decided to carry out an additional analysis using a technique called Factor Analysis. This procedure examines the matrix of correlations and systematically looks for clusters of variables that appear to be so closely related that they actually form new variables called factors. The process of Factor Analysis is more systematic than visually examining a correlation matrix and final results appear in table 15. These are Factor Loadings which are correlations of the variables with the factors.

The table indicates that of all the vision variables there are basically four factors operating in the data base that is currently present.

Factors are usually named based on the variables which make them up. The first factor contained variables that related to the size of the average saccades and the average size of the participant's pupil. Why these are related is unclear at this time. The second factor contained variables that were highly correlated and represented different measures of saccade duration. In addition, the visual efficiency variable loaded on factor 2. This is not difficult to understand, since visual efficiency is computed using saccade data as a component of the numerator of the formula. The third factor concerns primarily fixation data to include the fixation means and medians along with the fixation frequency. Eye motion workload also loaded on that factor. It has saccade frequency as a major component of its formula; this is directly related to fixation frequency since each saccade ends in a fixation. The fourth factor was pupil motion workload by itself. As shown in the correlation matrix it did not correlate with any other vision variable and, therefore, formed its own factor.

TABLE 15. FACTOR LOADINGS FOR VISION VARIABLES

Variable	Factor: Magnitude/Pupil	Duration	Fixations	PUPMOTWL
FIXMEAN			-.876	
FIXMDN			-.880	
SACDURM		.992		
SACDURMD		.880		
SACMAGMN	.989			
SACMDN	.944			
PUPMEAN	.795			
PUPMDN	.780			
FIXFREQ			.885	
VISEFFIC		-.945		
EYEMOTWL			.894	
PUPMOTWL				.997

Pearson product-moment correlations were also computed between the performance variables to include over the shoulder ratings by a subject matter expert seen above and the vision data collected with the oculometer. Table 16 provides all of these correlations. This table contains a great deal of data and is rather visually noisy.

The easiest way to read this table is to scan across each row of the performance variables and attempt to identify those relationships which exceed the critical value of r=.44. This is the minimum correlation that would be significant from zero.

TABLE 16. CORRELATIONS BETWEEN PERFORMANCE AND VISION

	PERF RTG	FIX MEAN	FIX MDN	SAC DURM	SACD URMD	SAC MAGMN	SAC MDN	PUPIL MEAN	PUPIL MDN	FIX FREQ	VISE FFIC	EYE MOTWL	PUPIL MOTWL
Skill	-.54	.11	.14	.24	-.20	.01	.05	-.15	-.12	-.22	-.13	-.15	.09
TASKLOAD	-.04	.24	.29	-.12	-.20	.08	.11	-.02	.00	-.16	.20	-.05	-.16
LCNF	-.34	-.05	-.01	-.24	-.17	-.06	-.05	-.10	-.11	.10	.19	.04	.10
LAPI	-.35	-.03	.01	-.22	-.17	-.01	.00	-.02	-.04	.06	.17	.06	.07
MLAPI	-.31	.04	.05	-.11	-.13	.14	.15	.21	.19	-.04	.08	.09	-.05
SCNF	-.23	.09	.09	-.32	-.29	-.02	.06	.03	.02	.06	.29	-.03	.15
SAPI	-.18	-.14	-.13	-.15	-.05	-.29	-.28	-.29	-.29	.16	.08	-.12	-.11
MAPI	-.46	-.21	-.22	-.19	-.25	-.13	-.17	-.19	-.19	.30	.07	.16	-.05
BCNF	-.58	-.14	-.15	.47	.02	.22	.12	.09	.09	-.12	-.42	.12	.34
BAPI	-.23	-.03	-.01	-.16	-.34	.24	.23	.17	.16	.06	.13	.24	.05
MBAPI	-.46	-.23	-.19	-.19	-.34	.14	.07	-.02	-.02	.30	.08	.40	.19
PKEY	-.06	.06	.09	-.57	-.43	-.28	-.17	-.17	-.18	.26	.47	-.03	.03
LAND	.06	.18	.16	.22	.05	-.11	-.02	.20	.20	-.26	-.11	-.30	.31
WLRT	-.49	.14	.14	-.47	-.59	.11	.16	-.16	-.15	.10	.41	.15	-.15
PFRT	1.00	.41	.42	-.16	.18	-.12	.04	.18	.18	-.37	.31	-.47	-.21

Beginning with skill, only performance rating was significant. It was an inverse relationship because of the way the participants were coded: FPL 1 and Developmental 2. No vision variables correlated significantly with either skill or taskload. This held true for the next six performance variables. BCNF correlated against saccade duration means (SACDURMN). BAPI and MBAPI did not correlate against any performance variables. PKEY was the measure of the pilots key strokes in response to controller verbal instructions. It correlated with three vision variables: SACDURM, SACDURMD, and VISEFFIC. These three variables all contain information related to saccade duration. **It appears that controller activity level is inversely related to saccade durations; the busier he becomes, the shorter and more frequent are his saccades.** Workload rating by the over the shoulder observer was also inversely related to saccade durations. **The shorter the saccades the higher the perceived workload as rated by the observer.** It is unlikely that the observer was keying in on the eye movements themselves, but rather he was focusing on the situational demands of the environment created by the simulation. Eye motion workload EYEMOTWL was inversely related to performance ratings. The reader will recall that EYEMOTWL loaded on the same factor as the fixation frequency and duration measures although it contains saccade information. It may well be more sensitive to performance rating than the fixation data, which did not correlate significantly with the PFRT.

One of the principle issues in this study was whether or not fully trained controllers behaved differently than developmental controllers. Unfortunately, because of the sampling used, these two groups of people differed more in terms of their familiarity with the specific airspace they were working than based on years of experience (i.e., most of the developmentals had come from other facilities). Regression analysis was employed to determine whether there were vision variables that could separate the participants based on their skill levels: FPL's 1 and Developmentals 2. Regression offers more power in looking for relationships than do simple bivariate correlations just discussed. It provides an opportunity to maximize the contributions of number of predictor variables (in this case vision variables) against a criterion variable. The criterion here was skill level, which unfortunately was a dichotomous variable. It is more difficult to obtain a viable relationship against a dichotomy than against a continuous variable which has more information. It would have been better if skill could have been graded along some sort of continuum. However, the regressions were computed with what we had.

Applying regression analysis to data like this might be likened to applied chemistry, you try alternative mixtures until something interesting occurs. In regression, you have a number of alternatives. The first is standard regression. This enters

all the predictor variables and produces an equation which shows how they fit against the criterion. Standard regressions were run against skill, and nothing was significant. Standard regressions throw all the variance available into the pot, and with it comes considerable error variance along with the relationship information of interest. Another alternative is a step wise regression in which the computer evaluates the potential contribution of each predictor and steps them into the equation until it is told to stop, usually at a point where there is certain amount of error remaining in the system. The researcher can also tell the computer to stop after a certain number of steps. The result will be a regression limited to a given number of variables. This was the process that was employed. Based on what amounted to trial and error, it was determined that the strongest regressions could be achieved using step wise regression limited to six steps.

Regressions were computed against skill, taskload, workload rating and performance ratings. Table 17 describes the overall results of those analyses.

TABLE 17. REGRESSION ANALYSES ON VISION VARIABLES

Criterion Variable	Multiple R	ANOVA on Regression
Skill	.857	F=5.59 **
Taskload	.464	F=2.33 NS
Workload Rating	.710	F=5.41 **
Performance Rating	.563	F=2.49 NS

* P<.05
** P<.01
NS-Not Significant

Selected vision measures produced a significant regression for skill as a dependent variable. The regressions was also significant for workload ratings but not for taskload or performance ratings. The lack of any workable regression for taskload was not too surprising since it did not correlate well with any of the vision variables, indicating that by itself **taskload did not have any noticeable impact on the vision results and performance ratings, as a whole, were not predictable based on vision data alone.**

Table 18 provides the beta weights for each of the significant regressions. The beta weight is an indicator of the degree to which each variable that entered the regression was successful in accounting for variance in the criterion variables.

TABLE 18. BETA WEIGHTS ON SIGNIFICANT VISION VARIABLE REGRESSIONS

Criterion	Vision Variable	Beta Weight
Skill	FIXFREQ	-1.77
	SACDURMD	-1.29
	PUPMEAN	- .71
Workload Rating	PUPMEAN	- .68
	SACDURMD	- .53

The sign of the beta weight is informative in that it indicates whether the variable should be added to or subtracted from the equation. Variables with a negative sign lower the predicted value of the criterion variable towards skill 1 and predict FPL, while those with a positive sign increase the value of the equation and predict towards a 2 or developmental controller. For example, fixation frequency under skill has a negative beta weight. Referring back to table 13 under fixation frequency, **it appears that FPL's have a higher mean of fixations. The regression indicates that higher fixations should predict lower controller skill code, in other words, an FPL controller.** When examining the means of the variables that entered the regression, it does not appear as though there can be much difference between the groups because of the nature of the measurement. With the exception of fixation frequency, in which it is clear that developmental controllers have fewer fixations, the other measures are more subtle. Saccade duration is in milliseconds. Saccade magnitude is in degrees of rotation, and it does not take much of a rotation to change things in the person's field of few. Things happen fast with eye movements. **The results of this analysis indicate that full performance level controllers search their environment more frequently than their less experienced colleagues.**

Judging from the correlation of workload ratings and saccade duration medians SACDURMD of -.59 and the regression in which pupil mean and SACDURMD both loaded negatively, it appears that lower workload ratings are associated with longer saccade durations, shorter magnitudes, and larger pupil sizes. The observer apparently was keying on dimensions of workload that could be associated, in part, with the controllers visual activity. It is unlikely that the observer was using this information directly and was probably cuing on other variables.

To this point in the analysis, the data has been dealt with in a specific manner. Due to the large volume of data generated by the oculometer, it was necessary to break the information into

reasonable chunks for further evaluation. These blocks of data were in 30-minute parcels, which were summarized during the initial data reduction by computing descriptive statistics, such as means and medians, and then using these descriptives to represent the parcel or block from which they arose. The descriptive then became the number which entered subsequent analyses. This has the advantage of greatly simplifying the process and the disadvantage of discarding a great deal of variance that could be useful if there were analytic resources to deal with it.

In order to evaluate the possibilities using a smaller data chunk size given the resources available, a select number of variables were chosen and were reduced to the 5-minute level. The data that were then statistically analyzed were the descriptive statistics for each of the 5-minute blocks within each of the 30-minute simulations. The variables chosen were saccade magnitude (SACMAGMN), saccade duration (SACDURM), fixation frequency (FIXFREQ), and fixation duration (FIXMEAN).

The analyses of these four variables examined the potential impact of skill, taskload, and time sequence on the vision data. The data for the variables were plotted and are presented in figures 3 through 6. For both saccade magnitude and duration, the plots took on a characteristic shape indicating what appeared to be a decline over time. A three-way ANOVA was computed on saccade magnitude with taskload, skill, and time as independent variables. There were no significant interactions or main effects for taskload or skill ($P>.05$). However, there was a significant effect of time ($F=165.11$, $P<.01$). Deleting the first time block and running the analysis again led to a significant time main effect, but of smaller magnitude ($F=16.93$, $P<.01$). With saccade duration the results were similar. There were no interactions and only one main effect, time when including all six time blocks ($F=10.52$, $P<.01$). When the first time block was removed, then the time main effect was no longer significant ($F=.568$, $P>.05$). **It is apparent that over the first 5 to 10 minutes of scanning there are significant changes in saccade magnitude and duration. Both decreased then stabilized for the remainder of the 30-minute shift. It is well known that controller operational errors most frequently occur at the beginning of a shift or right after a break.**

Fixation frequencies, as described in figure 5, show no characteristic pattern. No interactions or main effects were significant including time ($P>.05$). The graph seems to indicate that developmental controllers, when under high task load, have lower fixation frequencies. They appear to be scanning less, but the ANOVA did not demonstrate this statistically. This could be due, in part, to the complex variability in the design coupled with the multiple sources of measurement error when analyzing the data as a whole. A little known nonparametric test was applied

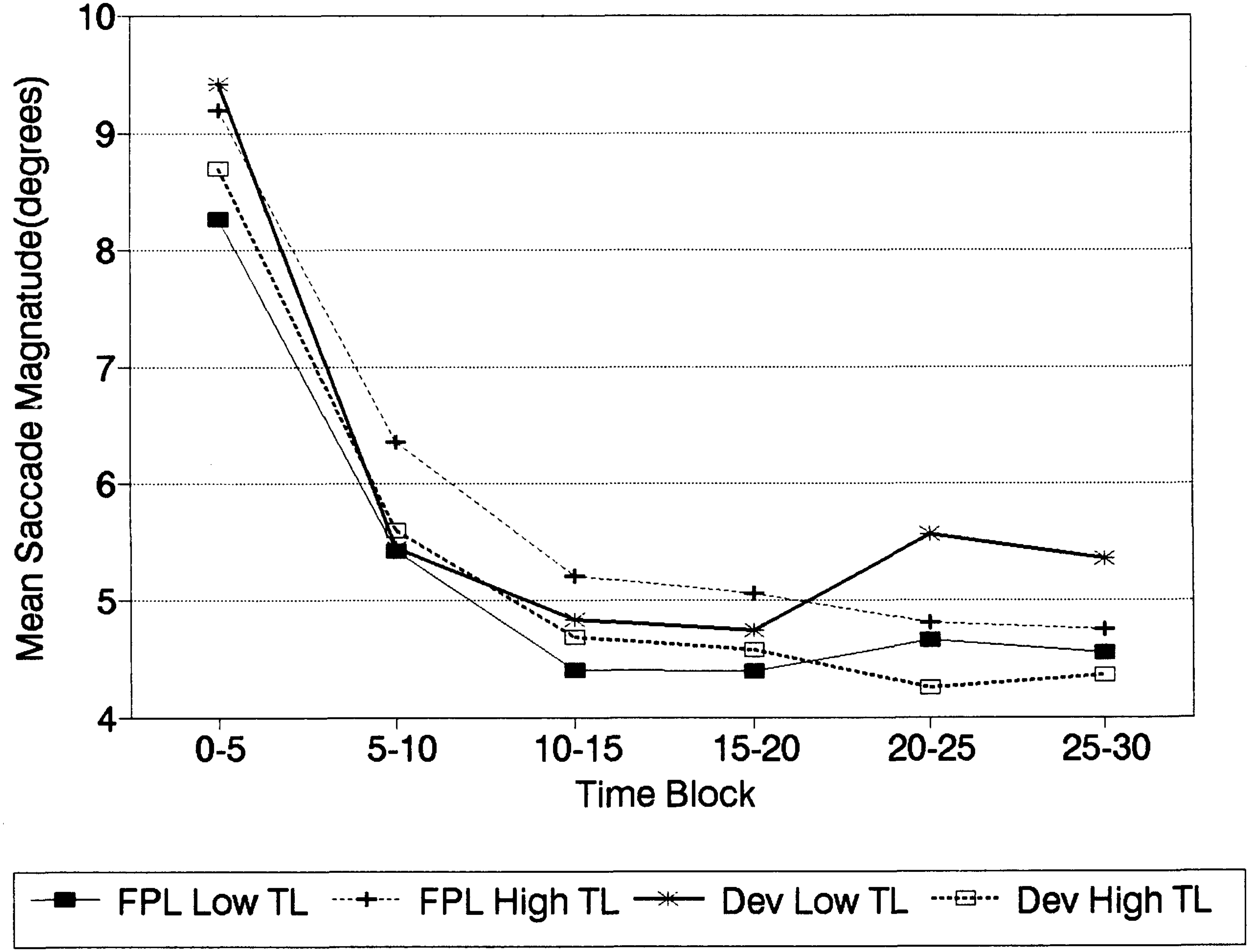

FIGURE 3. MEAN SACCADE MAGNITUDES

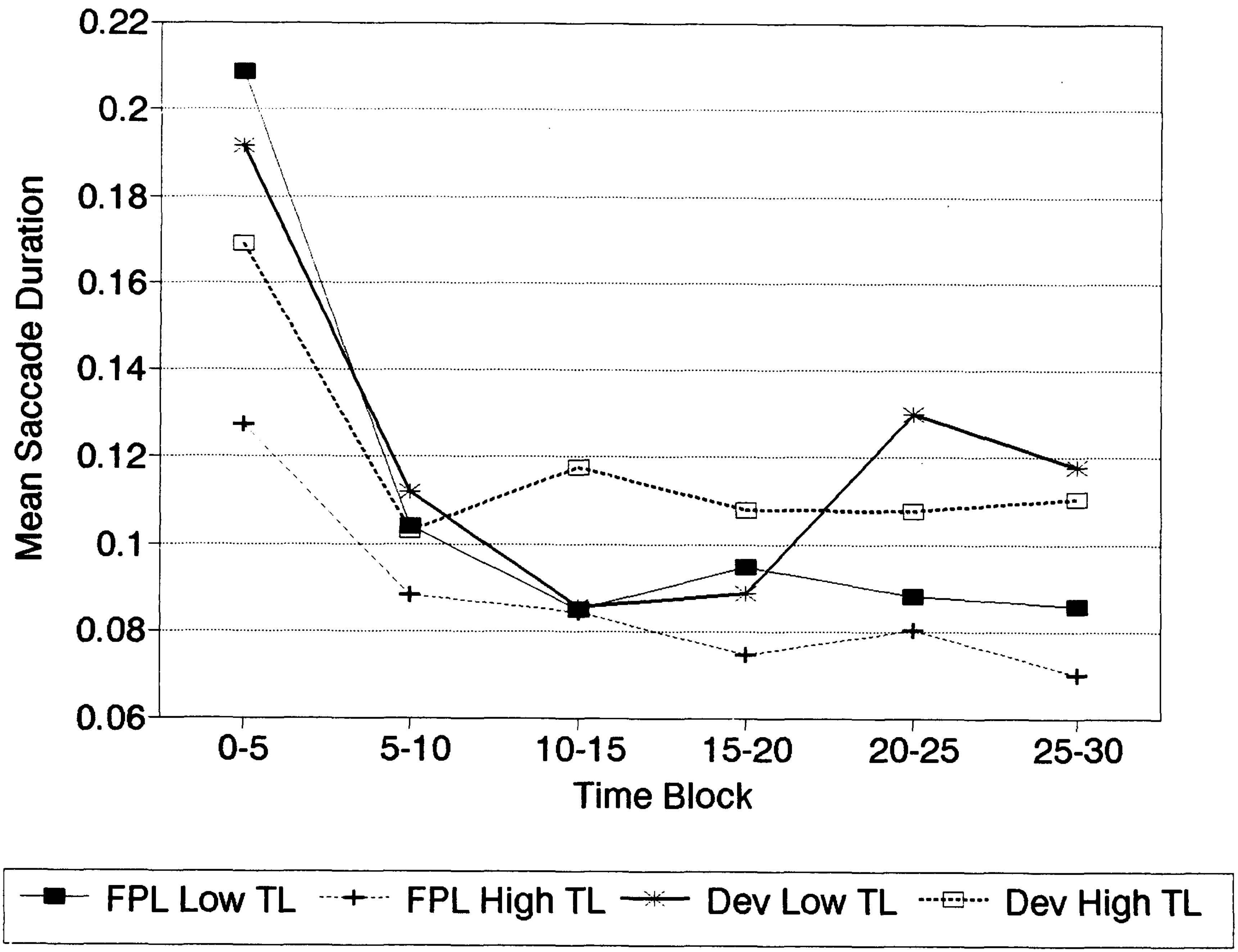

FIGURE 4. MEAN SACCADE DURATIONS

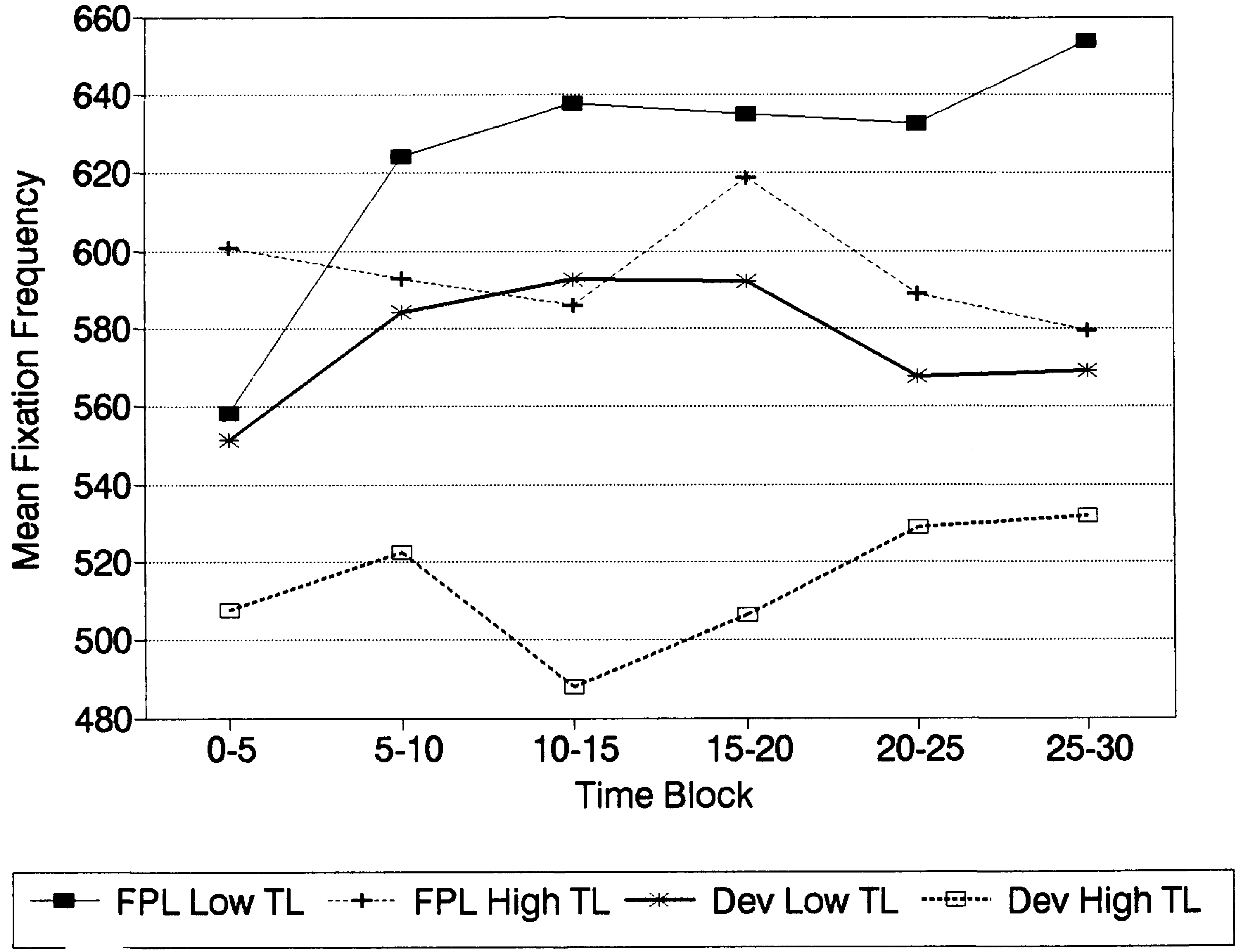

FIGURE 5. MEAN FIXATION FREQUENCIES

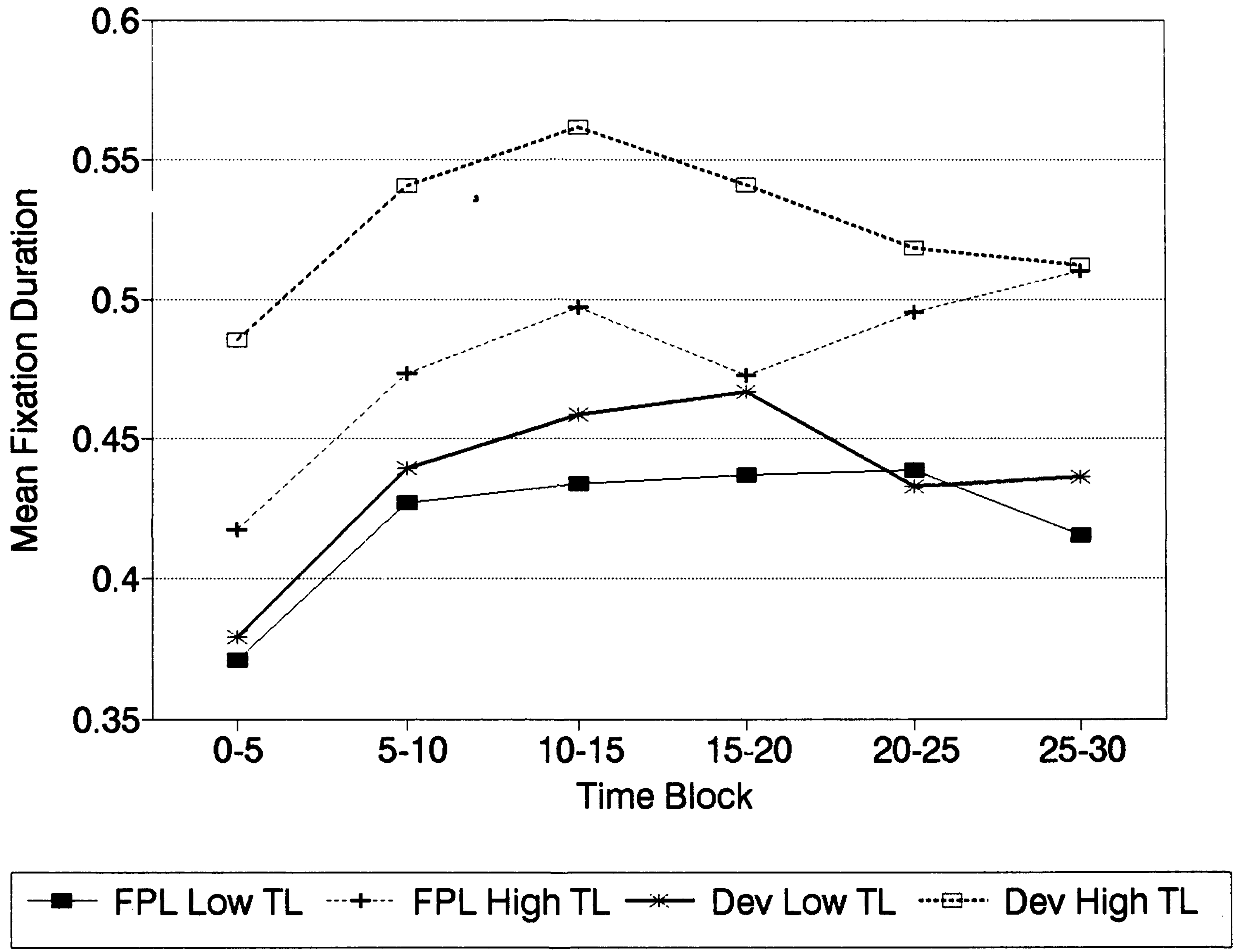

FIGURE 6. MEAN FIXATION DURATIONS

to the data within each time block. This technique, called the Wald-Wolfowitz runs test, looks at the order or sequence in which the original scores or measures were obtained (Siegel, 1956). It examines order only and attempts to determine if it could have occurred randomly or if there was some system or method to it. A significant test result indicates that it is unlikely that events are random. When Wald-Wolfowitz was applied to each of the time blocks on fixation frequency, two blocks were significant: the 10- to 15-minute block ($Z=2.686$, $P<.01$) and the 20- to 25-minute block ($Z=2.207$, $P<.05$). Using a remote test such as this could be rightly construed as reaching very hard for significance and no general conclusions should be drawn concerning fixation frequency and the various time blocks.

Fixation durations are plotted in figure 6. A three-way ANOVA was computed and results indicated no significant interactions and no main effects for skill or taskload ($P>.05$). There was a significant effect on time ($F=5.23$, $P<.01$). When the first time block was removed, then the time effect was no longer significant ($F=1.29$, $P>.05$), indicating that saccade durations increased during the beginning of a shift but not subsequently after the first 5 minutes. There were no differences within time blocks using Wald-Wolfowitz or any other statistical technique. **Fixation durations increased significantly during the first 5 minutes or so of a shift, then stabilized for the remainder of the scanning period.**

SCAN PLOT QUALITATIVE ANALYSIS.

The oculometer used in this experiment provided the opportunity to plot the results of each simulation in terms of fixation frequencies and magnitudes overlaid on a relative frame of reference. This means that while the system did not have the capability to provide specific point of gaze information such as what aircraft a controller was scanning, it could provide the pattern of fixations relative to each other. This pattern, coupled with a knowledge of the airspace geometry, provides a qualitative indicator of how controllers scanned over time. Further, the pattern and the frequency of longer duration fixations indicated graphically by larger circles depicting fixation points can be compared rather easily to the data just discussed above.

It was decided to plot each set of oculometer data in 5 minute blocks so 1/2 hour simulation consisted of six plots presented on two pages. Since each of the ten participants had two 1/2 hour simulations with the oculometer, the total number of plots was 20 x 6 or 120 in all. Rather than present them here, they are provided in total in appendix C. They are organized in two groups based on the participants skill level. Each set of plots is presented in the order of the simulation runs regardless of the order of task loading which, for the most part, did not make

much difference anyway. The reader may wish to review these plots before or during the following brief qualitative summary of what the plots may mean.

It is known from the previous analysis that fixation duration increases over the first minutes or so, or the scanning period. This would be depicted graphically as an increase in the number of larger circles as one moves from the first plot within each run to the second and occasionally to the third. By the third plot, fixation durations are relatively stable. The plots support the previous numerical analysis. While there was no measure of point of gaze, the patterns of the plots and the changes over time blocks were informative. The controllers were working the southern approaches and were vectoring aircraft to a final approach from west to east on a right parallel runway. The fixation patterns indicate a varied search over the first 5 minutes or so then a concentration over time as the traffic pattern developed. Particularly for FPL controllers, the largest clusters of fixations were on and around the turn point from base leg to final approach. There was more variability among the developmentals, some of whom did not concentrate as consistently on the turn point. It is not possible to determine from these plots what the relative order of fixations were and the magnitude of the saccades between the fixations.

The plots confirm that it takes 5 to 10 minutes for the scan pattern to stabilize when the traffic flow is building and the controller enters a cold display. This was induced, in part, because the traffic pattern and flow had to build over time as simulated aircraft entered. It is likely that it would still take a few minutes for the controller coming on to a position to develop his/her situation awareness and identify the best scanning strategy for the situation. Ideally, this should happen prior to relieving the other controller. If the new controller says "I've got it" too soon, he may well miss critical information because he is not adequately scanning the airspace. **The plots support a hypothesis that, at least in the situation described by the simulation, airspace geometry and traffic flow are major determiners of scan pattern.**

PERSONALITY AND AIR TRAFFIC CONTROL.

Every air traffic controller is tested extensively when they enter the profession. One of the tests they take is called the "Sixteen Personality Factor Questionnaire (16 PF)." This is a trait based measure which attempts to identify where people are on 16 dimensions of personality that were developed over 40 years ago based on factor analyses of all the personality trait inventories available at the time. The 16 factors are listed in table 19.

The 16 PF has evolved into one of the most heavily used and researched personality questionnaires in the history of psychological measurement. The author of this report has used it successfully in previous research, and it was decided to administer the questionnaire to the participants to see if any differences existed between the developmental and FPL controllers (Stein and Meiselman, 1977).

They are designated by letters with the exception of the last four which have letters and numbers. As indicated earlier in the description of factor analysis, factors are usually named based on the variables that load on them. The authors of the test in the version used for this experiment were very creative and somewhat pedantic when they named the factors (Cattell, Eber, and Tatsuoka, 1970). For example, Factor "A" is referred to as the Sizothymia-Affectothymia factor. Since such words do not have much meaning to the general public or to many psychologists any more, words in more common usage were selected to help explain the results.

TABLE 19. DEFINITIONS OF 16 PF FACTORS

Factor	Low Score	High Score
A	Reserved	Outgoing
B	Less Intelligent	More Intelligent
C	Emotional	Calm
D	Undemonstrative	Overactive
E	Dependent	Independent
F	Slow, Cautious	Quick, Alert
G	Frivolous	Responsible
H	Shy	Adventurous
I	Self Reliant	Insecure
L	Trusting	Suspicious
M	Practical	Imaginative
N	Unpretentious	Worldly
O	Self Assured	Apprehensive
Q1	Conservative	Experimenting
Q2	Follower	Leader
Q3	Uncontrolled	Controlled
Q4	Relaxed	Tense

The 16 PF consists of a series of questions in which the respondent is asked to indicate the degree to which certain statements like "I like to watch team games" apply to him. The questionnaire is scored for a raw score which is compared against a standardization sample, the results of administering the questionnaire to many people. The result is a Standard Ten Score (STEN) score on each of the 16 factors. A STEN relates the individuals raw score against the performance of the group in the standardization sample. The mean of the distribution of STEN scores is 5.5. The range from 5 to 6 covers one standard

deviation and the authors suggest that only steps that are at or below 4 or equal or exceed 7 should be considered as having departed from the average.

Using this information helps interpret figure 7, which maps the mean results for the ten controller participants on the 16 PF. This figure indicates that there may have well been differences between FPL and developmental controllers at least on some dimensions. Figure 7 indicated that there were a number of dimensions where one group or the other diverged from the average and met or exceeded the 4 or 7 STEN score cut points. A low score on factor "E" for the developmental controllers demonstrated that, on average, they responded on the 16 PF that they felt dependent and humble. This was not the case for the more confident FPL's. A very low score on factor "M" by the developmental controllers indicated a focus on practical concerns and, according the 16 PF handbook, that they may have felt concerned or worried when they completed the questionnaire. A high score on Q2 for the FPL's indicated that they felt considerable self-sufficiency and resourcefulness, which is characteristic of controllers as a whole. The developmentals also were about a half a standard deviation above the mean on this variable.

In order to determine whether there were any differences between the two groups of controllers that occurred beyond the level of chance, a very basic statistical procedure was used. A "t" test was computed between the two groups on each of the 16 factors. The "t" test is like a subset of analysis of variance. It allows for a probability estimate that difference between two means may have occurred beyond a chance level. The results for the "t" tests computed are shown in table 20.

Only those t's that were significant from zero (P<.01) are reported in this table. Results indicated that the FPL's and developmentals were significantly different on 4 of the 16 factors. **The FPL's described themselves as more self-assured (E), more imaginative (M) than the developmental controllers. The developmentals, who may have been overcompensating, saw themselves as more worldly/shrewd (N) than did the FPL's, but admitted that they were more apprehensive (O). While the differences between the two groups were not significant on factor Q2, the FPL's did exceed the cut point of 7, indicating that they felt very self-assured and resourceful.**

These data are more relevant when it is noted that the 16 PF was not administered until the very end of the experiment, after all the simulations were completed. This suggests that the values achieved represented more than a response to the immediate situation and may have tapped more enduring characteristics of the ten individuals who participated in the study.

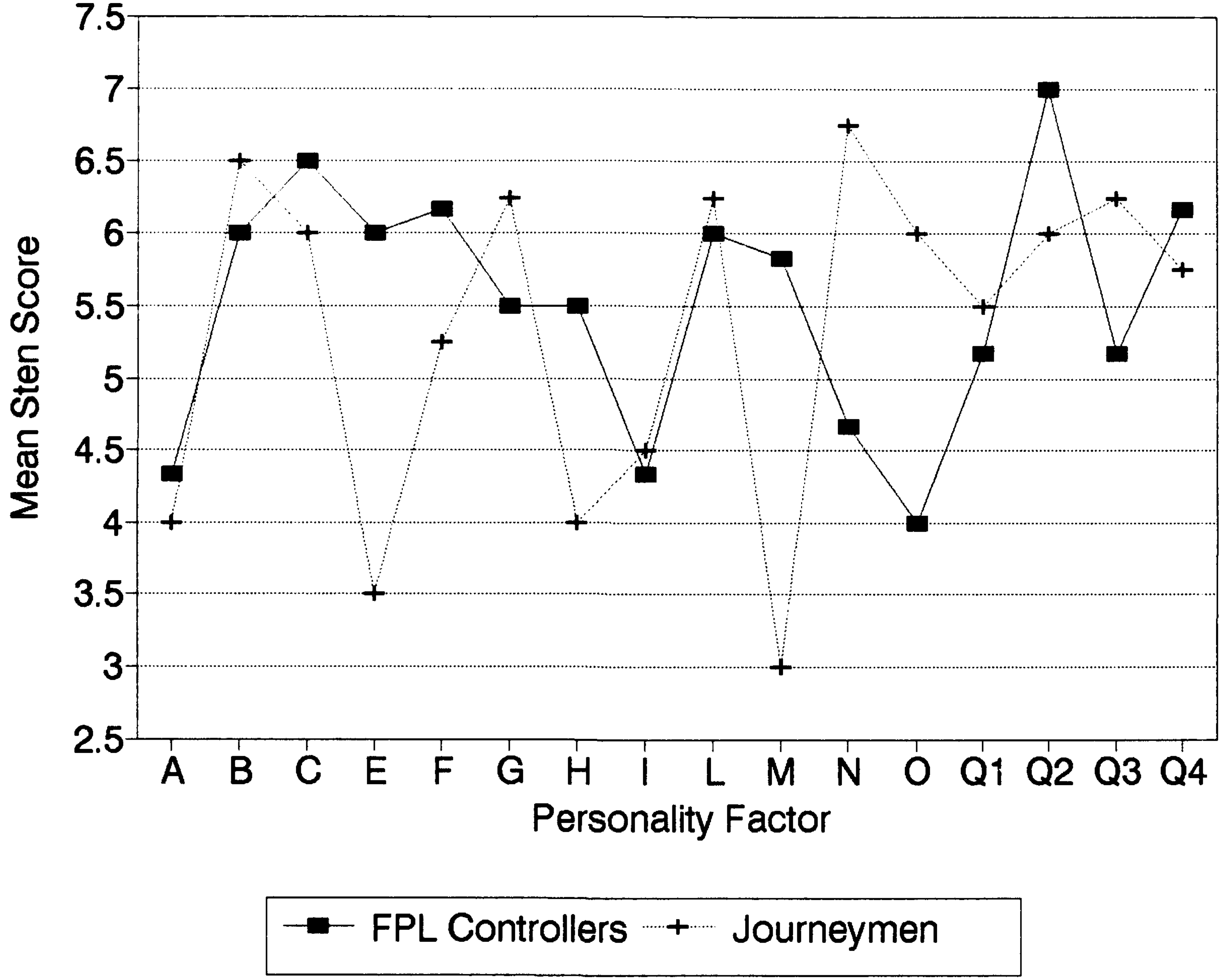

FIGURE 7. MEAN 16PF SCORES

TABLE 20. PERSONALITY DIFFERENCES BETWEEN CONTROLLER GROUPS

Personality Factor	t Value
E (Dependent-Independent)	3.93
M (Practical-Imaginative)	4.72
N (Unpretentious-Worldly)	4.67
O (Self assured-Apprehensive)	3.49

The results of the post-run attitude questionnaires which were administered after every simulation were described previously in this report. Given that personality is, in theory, more enduring than attitude and opinion measured by the questionnaires, the relationship between the 16 PF and questionnaire responses was examined. Pearson product-moment correlations were computed between the 16 factors and the questionnaire data, to which was added the observers' performance, workload ratings, and the number of landings achieved by the participants. Table 21 describes these correlations.

TABLE 21. PERSONALITY POST-RUN QUESTIONNAIRE CORRELATIONS

Questionnaire & Performance	16 PF FACTORS A	B	C	E	F	G	H	I	L	M	N	O	Q1	Q2	Q3	Q4
Skill	-.11	.21	-.12	-.54	-.23	.29	-.30	.06	.07	-.61	.60	.49	.11	-.24	.20	-.10
Workload	-.12	.25	-.37	.14	-.22	-.15	-.45	.14	.48	.16	-.11	.25	-.09	.39	-.54	.40
Perform	-.05	-.49	.59	.58	.63	.10	.51	-.42	.07	.16	-.68	-.55	.36	-.27	.40	-.23
Timecont	-.05	.05	-.23	.27	-.07	.05	-.42	-.03	.50	.12	-.09	.30	.06	.31	-.44	.12
Stress	.04	.38	-.50	-.21	-.27	.09	-.53	.12	.36	-.13	.17	.26	.07	.17	-.17	.18
Interfer	.21	.26	-.26	-.03	-.05	.19	-.27	.13	-.04	.02	-.07	-.14	-.24	-.08	-.02	-.13
Trafvolu	-.20	.04	.09	.48	.01	.00	-.27	.10	.55	.22	-.22	.18	-.21	.15	-.52	.03
Trafcomp	-.23	.16	-.05	.20	-.15	-.05	-.35	.14	.25	.09	.04	.33	-.34	.23	-.62	.24
Rylayout	-.44	-.32	.40	.31	.26	.19	-.14	-.13	.14	-.02	-.42	.06	.33	-.19	.06	-.34
ACedges	-.34	-.20	.42	.30	.38	.29	-.01	-.17	.30	-.26	-.43	-.04	.08	-.39	.17	-.10
Metering	-.40	-.35	.60	.71	.42	.07	.01	-.28	.09	.31	-.61	-.18	.16	-.01	-.23	-.19
Fatigue	.10	.07	.08	.06	.12	.42	-.27	-.18	-.12	-.07	.08	-.07	.20	-.18	.16	-.51
LAND	.32	.16	.02	-.17	-.01	.42	-.01	.02	.11	-.37	.51	.12	-.19	-.36	.28	-.42
WLRTG	.10	-.18	.08	.19	.21	.28	.07	-.19	.25	-.37	.08	.31	-.37	-.12	-.10	.17
PERFRT	.00	-.15	.51	.32	.33	-.02	.44	-.05	-.20	.26	-.41	-.63	.00	-.32	.31	-.33

Note: Underlined correlations are considered significant from zero.

In order to approach these data conservatively, it was decided to use the P<.01 level of significance to interpret the correlations. The critical value for correlation using this level of significance is r=.53. Only those which met or exceeded this value were considered as significant from zero beyond a chance level. Out of 240 correlations, only 15 were significant, and these are underlined in the table.

The significant correlations indicate a relationship between current responses to the immediate environment and what the controllers brought with them to the situation. In terms of skill level, factors

E, M, and N were significantly correlated. This was not surprising since it was already shown in an earlier analysis that these factors separated the two groups of participants. There was one 16 PF variable, Q3 (Uncontrolled-Controlled) that was related to self-assessment of workload in the questionnaire. **Those who defined themselves as more uncontrolled and spontaneous rated their workload during the simulations as higher.** Controllers' self-assessment of performance was significantly related to factors "C" (Emotional-Calm), "E" (Dependent-Independent), "F" (Slow/Cautious-Quick/Alert), "N" (Unpretentious-Worldly), and "O" (Self-Assured-Apprehensive). **Those who rated their own performance as higher saw themselves as more calm, independent, quick/alert, unpretentious, and self-assured.** There were no significant relationships for the third questionnaire item, the fraction of time actually controlling traffic (Timecont). The stress question was inversely related to factor "H" (Shy-Adventuresome). **Those who had less stress in the simulations scored more adventurous on the 16 PF.**

There were no significant correlations with the degree to which the participant felt the oculometer interfered with his performance. Controllers' perceptions of how traffic volume influenced their scanning were correlated with factor "L." **Those who indicated that they were more trusting on the 16 PF saw less of an impact by traffic volume.** The observed impact of traffic complexity was related to factor Q3 (Uncontrolled-Controlled). **Participants saw a greater impact of traffic complexity if they scored towards the uncontrolled end of factor "L."** Runway layout and aircraft at the edges of the display were not related to 16 PF data. The impact of metering on scanning was significantly correlated with factor "C" (Emotional-Calm), "E" (Dependent-Independent) and "N" (Unpretentious-Worldly). **Controllers who saw metering as more important for their scanning were more calm, independent, and unpretentious on the 16 PF.** There were no relationships of any magnitude between the 16 PF and the fatigue question on the questionnaire, the number of a landings the controller achieved, or the workload rating that the observer recorded. There was, however, an inverse correlation between the observer's performance rating and factor "O" (Self-Assured-Apprehensive). **Higher performance ratings were given to those who were more self-assured on the 16 PF.** This last finding is probably, at least in part, a function of the fact that the FPL's received higher performance ratings and were more also self-assured. The observer may have been relating in part to the FPL's confidence in their own skills.

Results of the correlations of 16 PF data with post-run questionnaires indicate that controllers respond to the immediate situation based, in part, on what they brought with them to that environment. Personality is one aspect of who we are, and it is related to how controllers view their surroundings.

EXIT INTERVIEWS.

At the end of the experiment, when all the simulations were completed, each of the participants was interviewed concerning his experiences and opinions. Each was asked to rate the realism of the simulation on a 10-point scale from 1=low to 10=high. The range of responses was from 3 to 10 with a median of 7. This is a reasonable response in comparison with previous studies using the NSSF simulation at the Technical Center. When asked, what aspects of the simulation were different from their home facility, everyone found something that was different. This included the fact that in the experiment flight strips were not used, and that the equipment in the NSSF was a little different in appearance from what they were used to operationally. They also noted that ordinarily they would have separate feeder and final approach positions. They were asked to do both, basically because there were not enough controllers. However, the task load was adjusted so that no one was overloaded during the experiment. The controller participants also noted that the aircraft performed at standard rates and more consistently than they do in the real world. This is an old problem with the simulation, which may be rectified by newer editions of the target generation functions and hardware.

Controllers were asked about their perceptions of the impact of the oculometer on their ability to control traffic. The responses ranged from constant awareness of the presence of the oculometer with some resultant annoyance, particularly from the helmet and the visor to the ability to tune out the equipment completely. This ability to ignore the equipment was based on distraction by the traffic and control requirements. Controllers indicated that as they became busier they noticed the oculometer less. Out of ten controllers, seven saw no oculometer impact at all on their performance. Two indicated that it bothered them only at the beginning of the experiment. One participant felt more tense when using the oculometer. He said he felt "under the gun."

When asked whether they had a specific strategy for scanning the planned view display, most controllers had to think awhile in order to review what it was they were actually doing. Almost all indicated that their scanning methods were situation dependent. Factors that they considered included: traffic volume and flow, the geometry of the airspace at the position being worked, aircraft speed compatibility, weather, flow control, and critical points. Verbalized strategies were in line with the scan plot qualitative analysis reported earlier. Controllers indicated that they focused on critical turn points such as downwind to base and base to final legs of the approach.

Controllers were asked if they had a characteristic style and preferences concerning separation techniques. Of specific interest was whether they preferred to use longitudinal or vertical separation. This question was not asked because its impact on visual scanning; rather, the goal was to determine whether the participants were

thinking like those in previous studies, and also to build an ongoing body of knowledge on controller behavior. Results indicated that while the majority of controllers believed that separation strategy should be tailored to the tactical situation, other things being equal, they preferred to use vertical separation techniques. This reduces workload because the controller did not have to keep estimating the distance between aircraft which is required if they are coaltitude. This result is consistent with previous research done at the FAA Technical Center in which the focus was parallel approach separation (Stein, 1989b).

Finally, controllers were asked if there was anything that should have been asked that was not or if there was anything they felt the experimenter should know. One controller expressed his displeasure with the oculometer helmet. A few again noted the differences between the simulation and their home facility, but did not have any major concerns with them. One indicated the equipment was fine, the experiment was well prepared, and the practice runs prior to data collection were useful. One controller commented that the FPL personnel would have performed even better if they had flight strips which he uses for planning purposes. Another controller suggested that more mistakes are made in ATC when they are not busy because their thinking wanders and it is easier to be distracted. While this did not relate directly to the scanning, it is in line with FAA error analyses. One of the developmental controllers, who had been a controller at another facility, said that the simulation of his current facility was a learning experience for him because he had not yet been radar qualified in his new job.

The controller visual scanning study was completed and the results indicated that their was form and substance to the way controllers reach out for information. In their own view, controllers each develop a style that works for them and they attempt to make the best use of it even though they may not be continually aware of what it is they are doing visually. When exposed to the quasi realistic environment of the simulations, they attempted to work with the equipment and live with the inconvenience of the oculometer. As always, controllers are adaptable and they work with what they have.

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APPENDIX A

TRAINING/FAMILIARIZATION PLAN

TRAINING/FAMILIARIZATION PLAN

PRIMARY OBJECTIVE.

Familiarize the participant controllers with the Air Traffic Control Simulation Facility and the airspace geometry which it simulates. Ensure that participants are able to control a moderate level of traffic, using the appropriate procedures and techniques.

ENABLING OBJECTIVES.

1. Condition: Given a routine air traffic sample of ten or less aircraft in sector.

   Task: The participant maintains communications with aircraft under his/her control and with adjacent controllers as required for intersector coordination.

   Standard: The participant employs standard radio telephone procedure, initiates contact to obtain required information or provide information and directives, accomplishes all necessary land line coordination with adjacent sectors.

2. Condition: Given a briefing and documents concerning operational procedures.

   Task: The participant demonstrates his/her knowledge and acceptance of these procedures through verbal discussion with the training controller.

   Standard: The training controller verifies that the participant has a working knowledge of procedures.

3. Condition: Given air traffic sample of ten or less aircraft of mixed types and flightpaths where potential conflicts, are preprogrammed.

   Task: The participant maintains radar surveillance, anticipates and identifies potential conflicts, and issues amended clearances.

   Standard: During a 1-hour simulation the participant controller does not allow more than two violations of the horizontal separation standard of aircraft within the vertical separation envelope and in no case are the violations allowed to progress to a point closer than 2 miles of separation.

4. Condition: Given an air traffic sample of 15 or fewer aircraft of mixed types and flightpaths where conflicts of separation may or may not occur.

Task: The participant exercises traffic management techniques to minimize delays and maintain a positive and expeditious traffic flow.

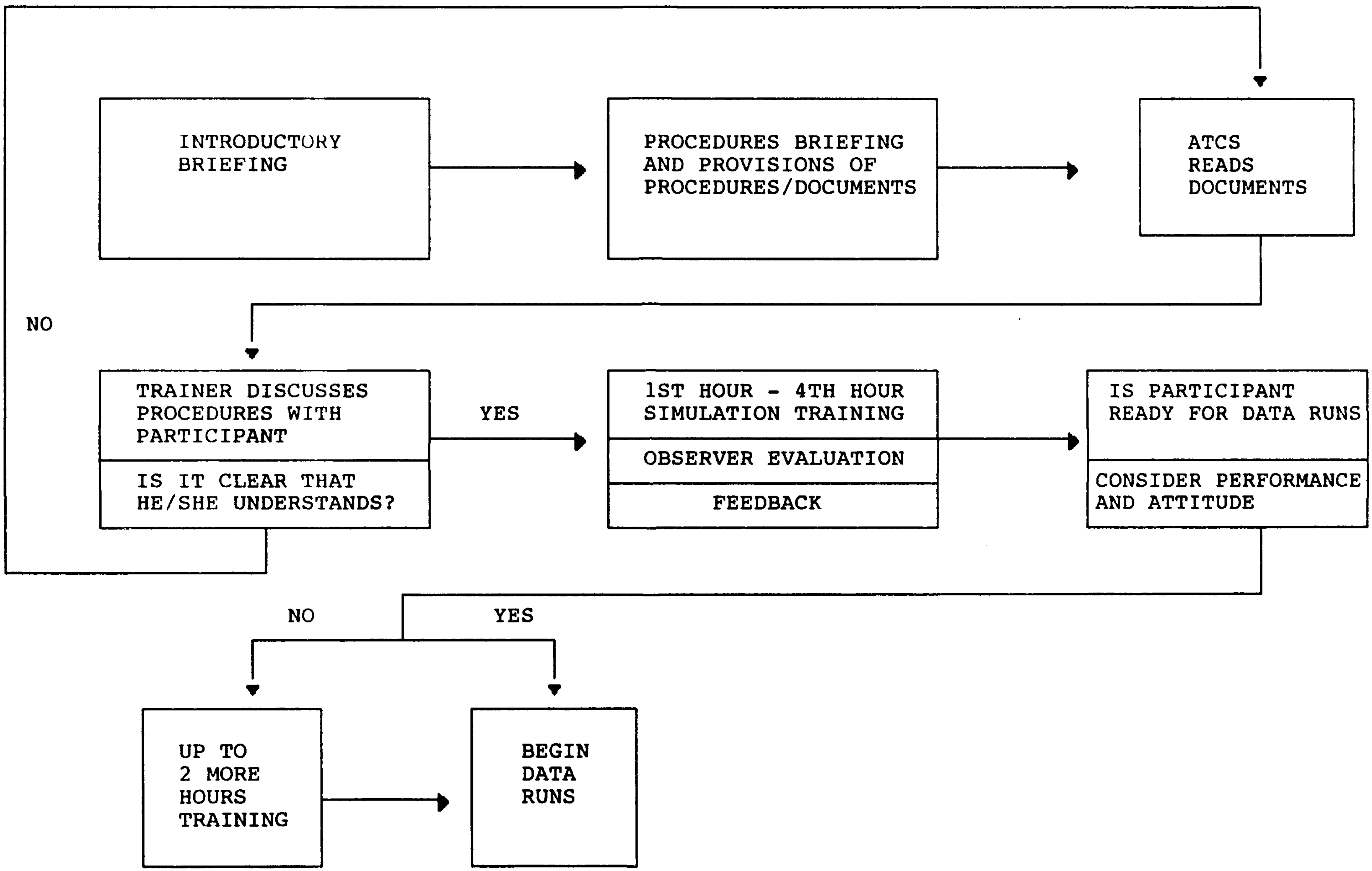
Standard: The controller maintains positive command of the traffic flow and introduces path changes only where necessary to maintain safe efficient traffic flow.

5. Condition: Given this training/familiarization program involving briefings, printed material and "hands-on" control of simulated aircraft.

   Task: The participant controller is able to control traffic.

   Standard: The participant is willing to state that he/she is adequately familiar with the simulation so that the simulation itself does not inhibit his/her performance.

TRAINING/FAMILIARIZATION FLOW



APPENDIX B

FORMS AND QUESTIONNAIRES

CONTROLLER SIMULATION QUESTIONNAIRE

INSTRUCTIONS

PLEASE COMPLETE THE FOLLOWING QUESTIONS AS SOON AS YOU HAVE BEEN RELIEVED FROM YOUR RADAR POSITION. YOUR RESPONSES SHOULD FOCUS ON ONLY THE WORK THAT YOU HAVE JUST COMPLETED IN THE LAST CONTROL PERIOD.

ALL CONTROLLERS EXPERIENCE A WIDE VARIETY OF ACTIVITY AND RESULTANT WORKLOAD DURING THEIR CAREERS. IT DOES NOT DETRACT FROM YOUR PROFESSIONALISM IF FOR A GIVEN PERIOD YOU REPORT VERY HIGH OR VERY LOW WORKLOAD. ON ALL THE QUESTIONS WHICH FOLLOW FEEL FREE TO USE THE ENTIRE NUMERICAL SCALE FOR EACH ANSWER. BE AS HONEST AND AS ACCURATE AS YOU CAN. YOUR NAME IS NOT RECORDED ON THIS OR ANY OTHER FORM, AND NO ATTEMPT WILL BE MADE TO ASSOCIATE YOUR RESPONSES WITH YOU AS AN INDIVIDUAL. DATA COLLECTED WILL BE FOR RESEARCH PURPOSES ONLY. THANK YOU FOR YOUR PARTICIPATION.

POST RUN CONTROLLER QUESTIONNAIRE

PARTICIPANT CODE_________ **DATE**__________

RUN NUMBER _________ **RUNWAY**_________

OCCULOMETER (Circle One) **yes no** **TIME**__________

1. CHOOSE THE ONE NUMBER BELOW WHICH BEST DESCRIBES HOW HARD YOU WERE WORKING DURING THIS PERIOD:

DESCRIPTION OF WORKLOAD CATEGORY	RATING (CIRCLE ONE)
VERY LOW WORKLOAD- ALL TASKS WERE WERE ACCOMPLISHED EASILY & QUICKLY	1 2 3
MODERATE WORKLOAD- THE CHANCES FOR ERROR OR OMISSION WERE LOW	4 5 6
RELATIVELY HIGH WORKLOAD- THE CHANCES FOR SOME ERROR OR OMISSION WERE RELATIVELY HIGH	7 8 9
VERY HIGH WORKLOAD - IT WAS BARELY POSSIBLE TO ACCOMPLISH ALL TASKS PROPERLY	10 11 12

---

2. RATE YOUR PERFORMANCE CONTROLLING TRAFFIC DURING THE PAST HOUR. CIRCLE THE NUMBER WHICH BEST DESCRIBES HOW WELL YOU THINK YOU DID.

1 2 3 4 5 6 7 8 9 10

AVERAGE ... **EXCELLENT**

3. WHAT FRACTION OF THE TIME WERE YOU BUSY DURING THE PERIOD YOU WERE CONTROLLING?

1 2 3 4 5 6 7 8 9 10

SELDOM HAD MUCH TO DO ... **FULLY OCCUPIED AT ALL TIMES**

4. RATE THE DEGREE TO WHICH YOU FOUND THIS CONTROL PERIOD STRESSFUL! CIRCLE THE NUMBER BELOW WHICH BEST DESCRIBES HOW YOU FELT.

1	2	3	4	5	6	7	8	9	10
LOW STRESS									HIGH STRESS

5. PLEASE RATE YOUR LEVEL OF AGREEMENT WITH FOLLOWING STATEMENT REGARDLESS OF WHETHER YOU USED THE OCCULOMETER DURING THIS LAST CONTROL PERIOD.

The occulometer did not interfer in any way with my performance during this control period!

1	2	3	4	5	6	7	8	9	10
Strongly Agree									Strongly Disagree

---

6. Below circle the number from 1-low to 10-high which best describes the influence of each of the following factors on how you visually scanned your radar display during the last period.

Traffic Volume	Low	1	2	3	4	5	6	7	8	9	10	High
Traffic Composition	Low	1	2	3	4	5	6	7	8	9	10	High
Runway layout	Low	1	2	3	4	5	6	7	8	9	10	High
Aircraft at the display edges	Low	1	2	3	4	5	6	7	8	9	10	High
Metering of inbound traffic	Low	1	2	3	4	5	6	7	8	9	10	High
Personal Fatique	Low	1	2	3	4	5	6	7	8	9	10	High

7. Briefly describe your strategy for working traffic during this control period.

8. IS THERE ANYTHING ELSE THAT HAPPENED THIS PAST HOUR WHICH YOU FEEL MIGHT HELP US UNDERSTAND THE RESULTS? ANY COMMENTS YOU HAVE AT THIS POINT WOULD BE VERY WELCOME.

FAA TECHNICAL CENTER
CONTROLLER ENTRY QUESTIONNAIRE

The purpose of this questionnaire is to find out something about your background and current feelings about this project in order to better understand your performance during the course of the study. All information is collected under your code number and no attempt will be made to link your name to to the answers you provide. Welcome to the Technical Center and thank you for your participation!

1.Participant Code: _______ Todays Date: _________

2.Your total experience as a Controller _________ years _________ months

3.Your experience at your current facility _________ years _________ months

4. Your current position: FPL, Developmental, other__________.

5. Please rate your current vision on the scale below:

1 2 3 4 5 6 7 8 9 10
Poor Excellent

Please indicate your level of agreement with each of the following statements by circling the most appropriate number between 1 Strongly Disagree and 10 Strongly Agree.

6. I freely volunteered to participate in this project.

1 2 3 4 5 6 7 8 9 10
Strongly Disagree Strongly Agree

7. I currently am in good health.

1 2 3 4 5 6 7 8 9 10
Strongly Disagree Strongly Agree

8.During the last several months, I have been experiencing a relatively high level of stress.

1 2 3 4 5 6 7 8 9 10
Strongly Disagree Strongly Agree

9. I am not very motivated to participatate in this study.

1 2 3 4 5 6 7 8 9 10
Strongly Agree Strongly Disagree

OBSERVER EVALUATION FORM

RUN NO ________ DATE__________

PARTICIPANT
OBSERVED _________ TIME__________

1. BELOW PLEASE CIRCLE THE NUMBER WHICH BEST DESCRIBES HOW HARD THE CONTROLLER WAS WORKING DURING EACH 15 MINUTE BLOCK OF THIS RUN.

FIRST BLOCK		SECOND BLOCK
1	VERY EASY	1
2		2
3		3
4		4
5		5
6		6
7		7
8		8
9		9
10	VERY HARD	10

2. BELOW PLEASE CIRCLE THE NUMBER WHICH BEST DESCRIBES CONTROLLER EFFECTIVENESS DURING EACH BLOCK OF THIS RUN.

FIRST BLOCK		SECOND BLOCK
1	AVERAGE	1
2		2
3		3
4		4
5		5
6		6
7		7
8		8
9		9
10	EXCELLENT	10

In this space please count or tally the number of times observed controller exhibits behaviors which are not related directly to control duties(ie talks to observers, looks away from the display)

First Block Second Block

Place any comments or other observations on the back of form.

CONTROLLER VISUAL SCANNING
EXIT INTERVIEW

DATE______________ PARTICIPANT_______

1.Please rate the realism of this simulation from 1 low to 10 high.

____

2. Was there anything that you found particularly unique in the simulation that you would not see at your home facility?

3. Think back to those runs when you were using the oculometer.

   Were you constantly aware of it or did you tune it out?

   After you wore it for a few minutes was it annoying?

   Did the use of the oculometer effect your performance in any way?

4. Think about how you search the PVD for information. Do you do it in one special way or does it depend on certain factors and if so what are they?

5. If you have a choice of separating aircraft vertically or horizontally which do you prefer to do and why.?

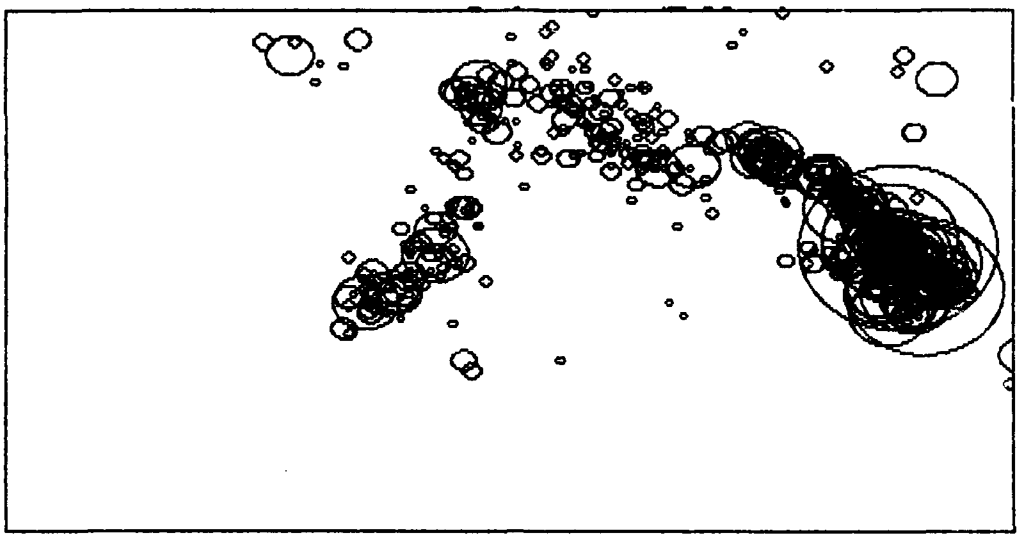
6. How do you decide whether or not to suppress data.

7. Is there anything I have not asked you or you think I should know which would help me understand what went on in this study?

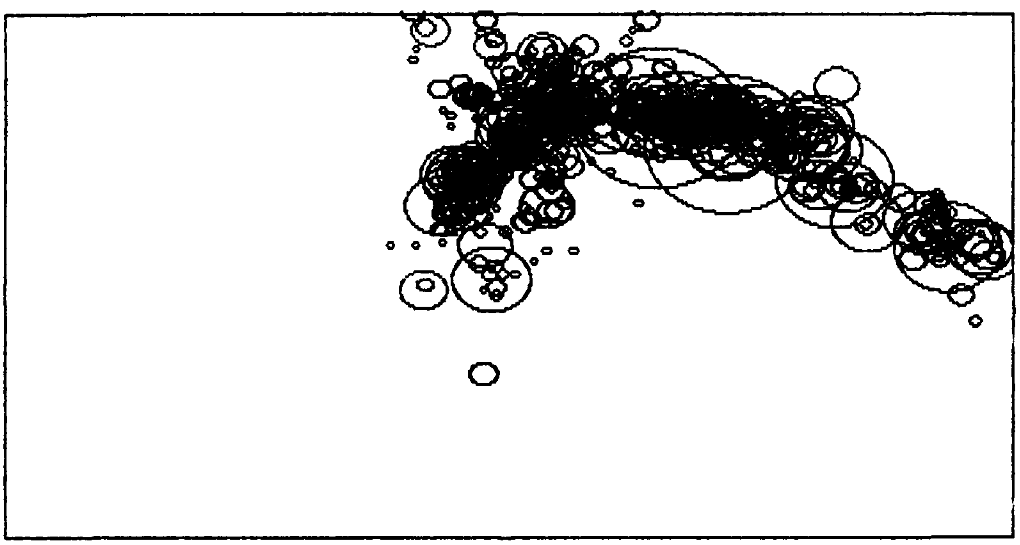
APPENDIX C

OCULOMETER PLOTS

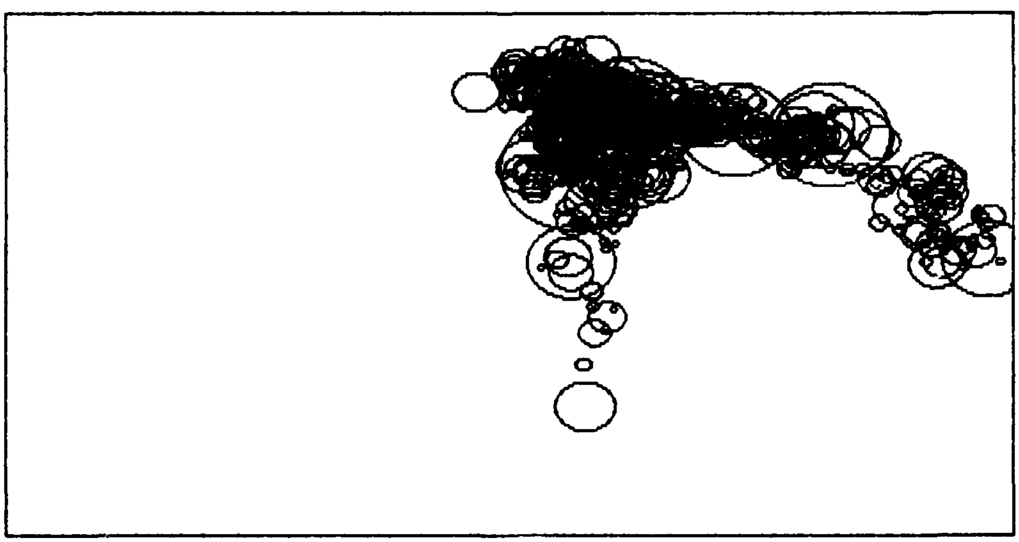
PARTICIPANT 01 RUN 1, 0-5 MINS H LOAD 9/6/90



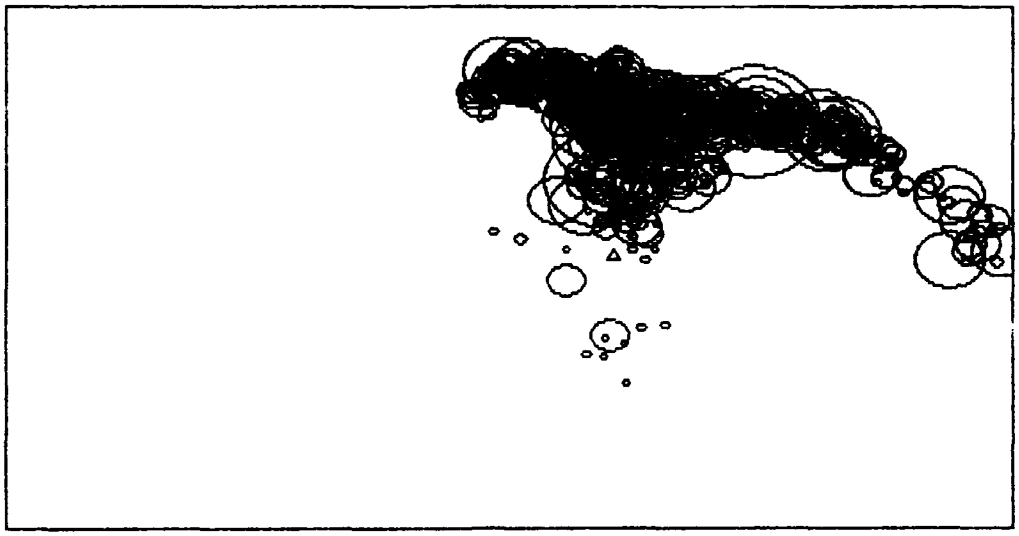
PARTICIPANT 01 RUN 1, 5-10 MINS H LOAD 9/6/90



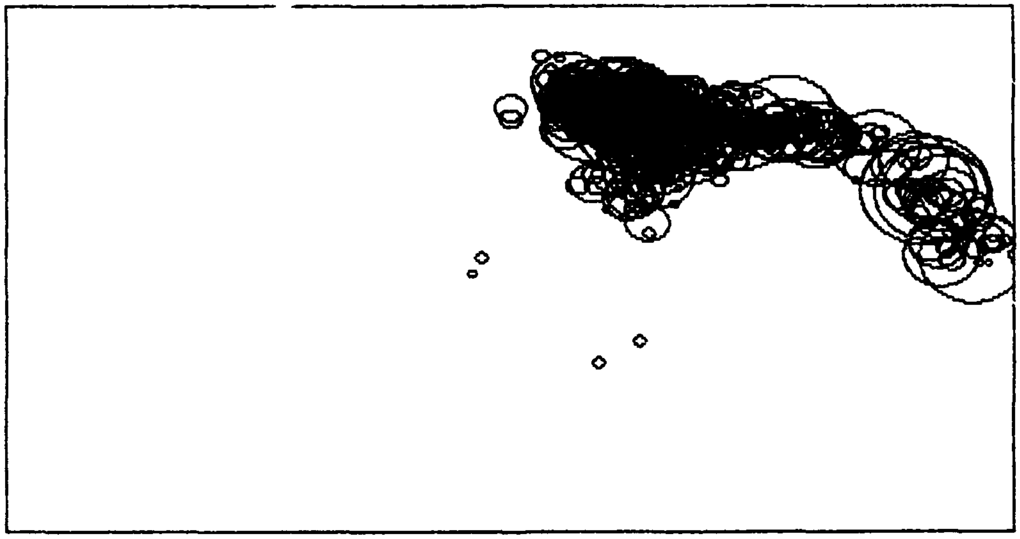
PARTICIPANT 01 RUN 1, 10-15 MINS H LOAD 9/6/90



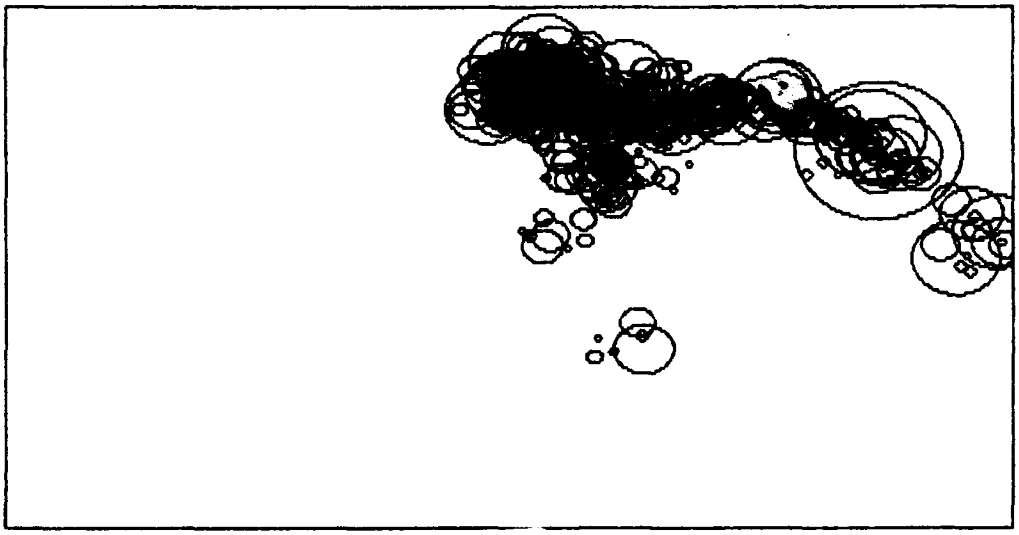
PARTICIPANT 01 RUN 1, 15-20 MINS H LOAD 9/6/90



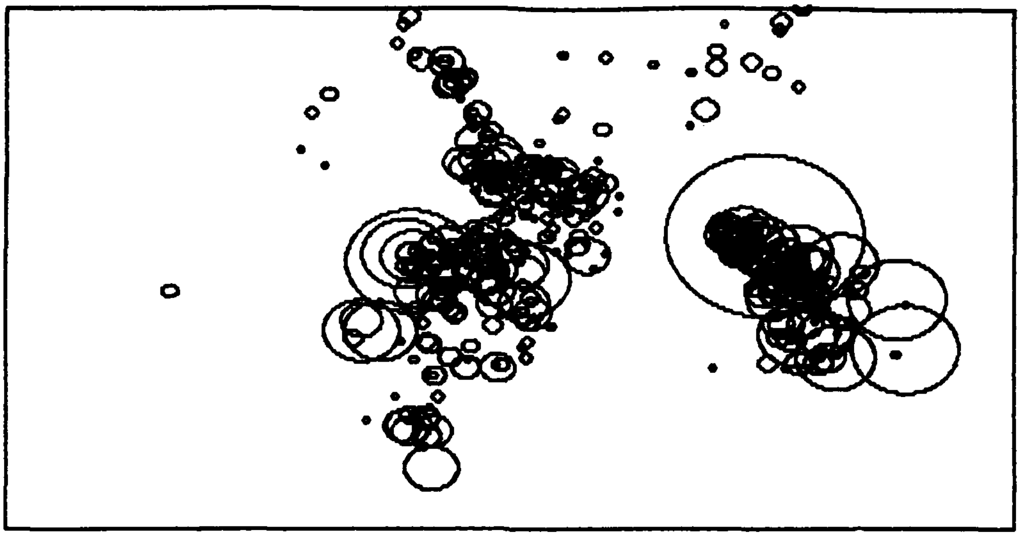
PARTICIPANT 01 RUN 1, 20-25 MINS H LOAD 9/6/90



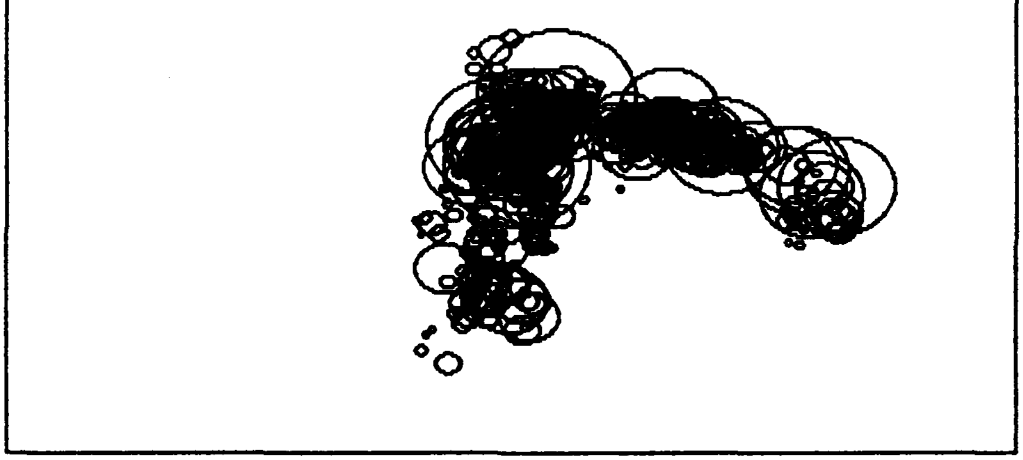
PARTICIPANT 01 RUN 1, 25-30 MINS H LOAD 9/6/90



PARTICIPANT 01 RUN 04, 0-5 MINS L LOAD 9/6/90



PARTICIPANT 01 RUN 04, 5-10 MINS L LOAD 9/6/90



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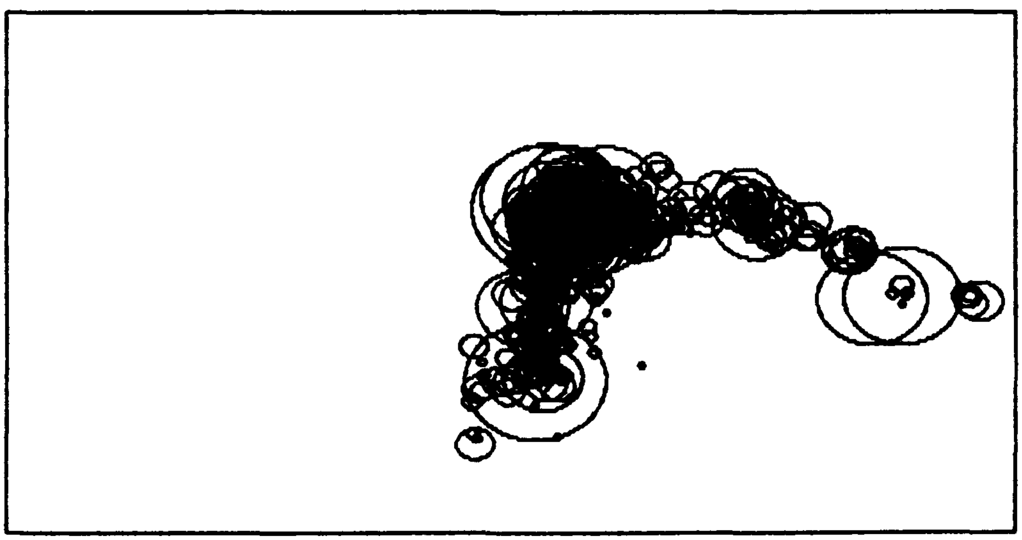

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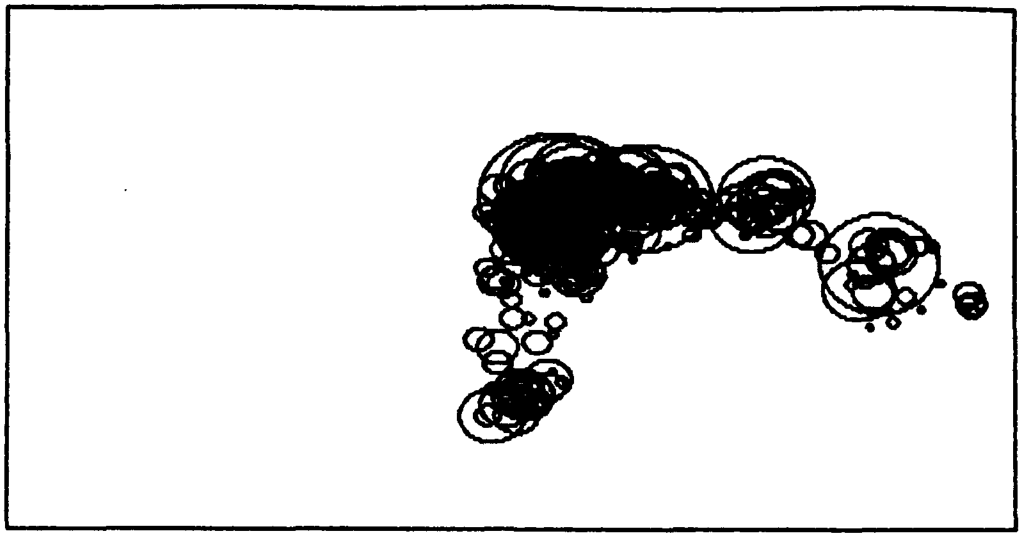

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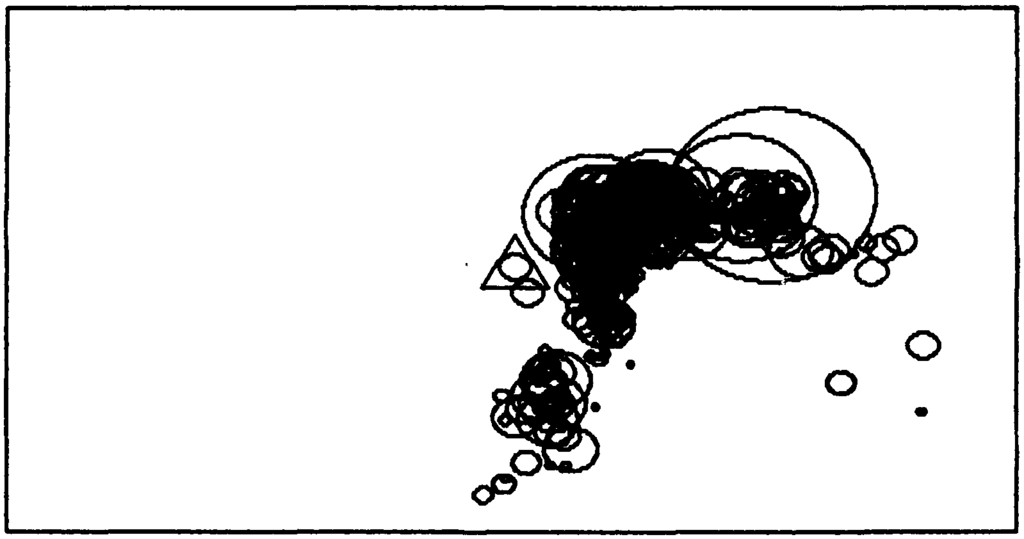

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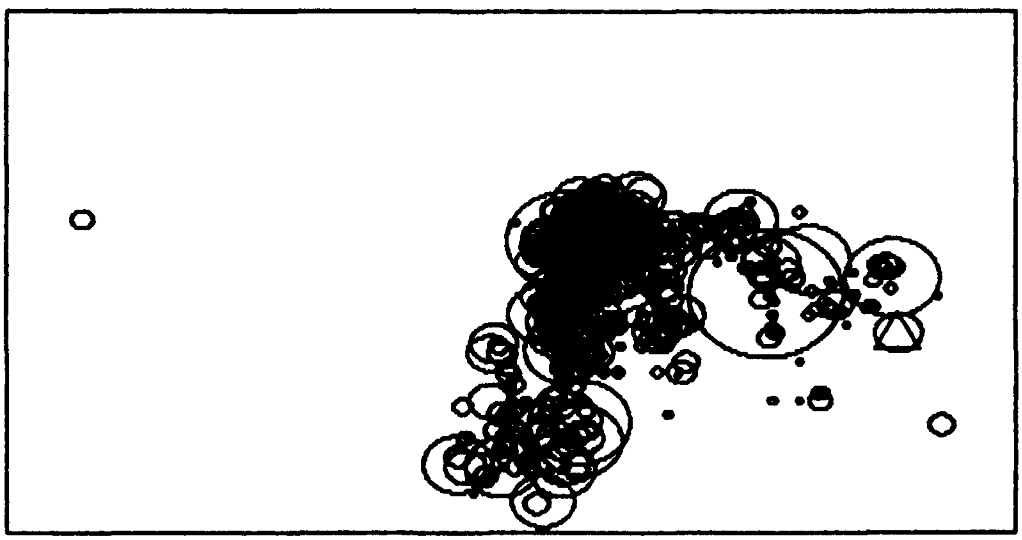
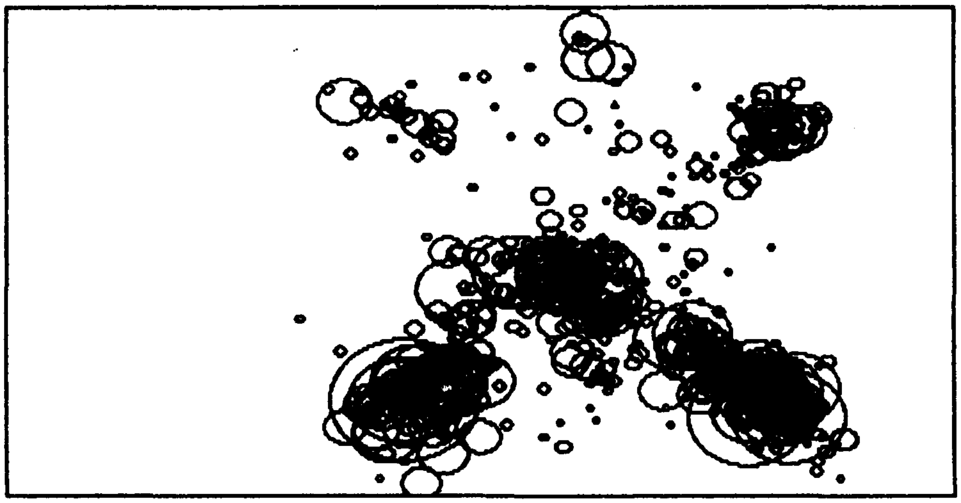
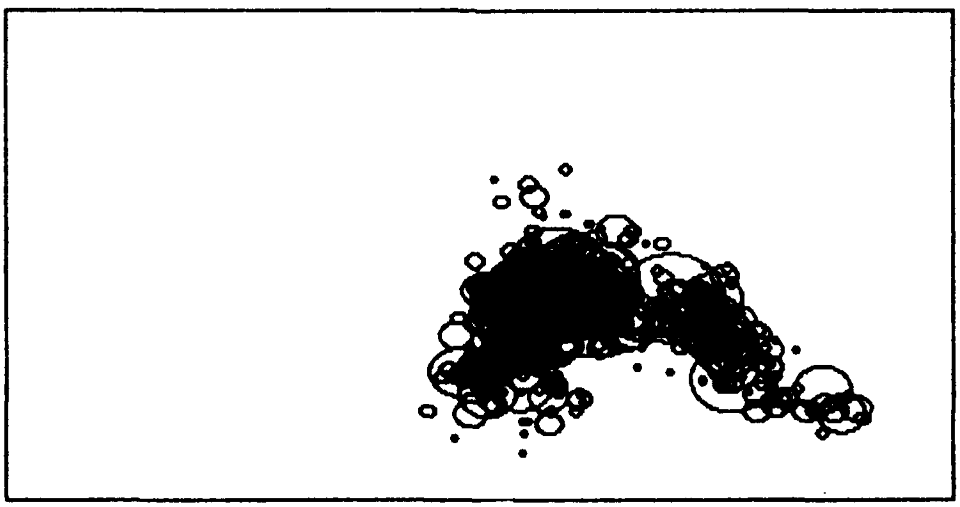


PARTICIPANT 03 RUN 12, 0-5 MINS H LOAD 9/11/90

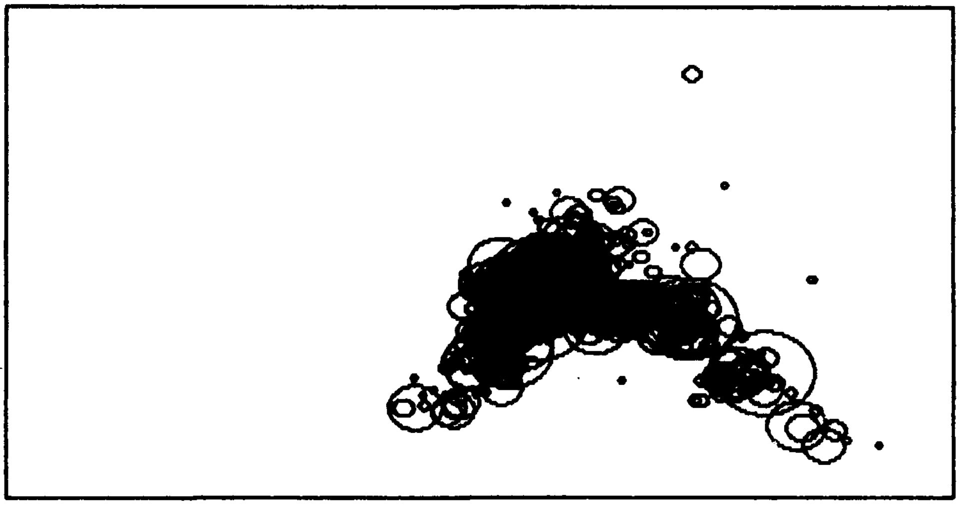


PARTICIPANT 03 RUN 12, 5-10 MINS H LOAD 9/11/90

PARTICIPANT 03 RUN 12, 10-15 MINS H LOAD 9/11/90



PARTICIPANT 03 RUN 12, 15-20 MINS H LOAD 9/11/90



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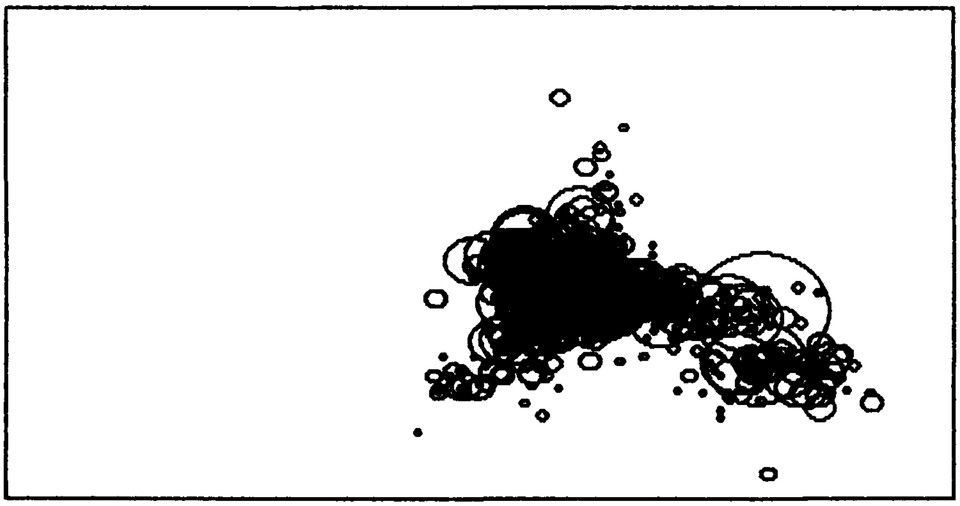

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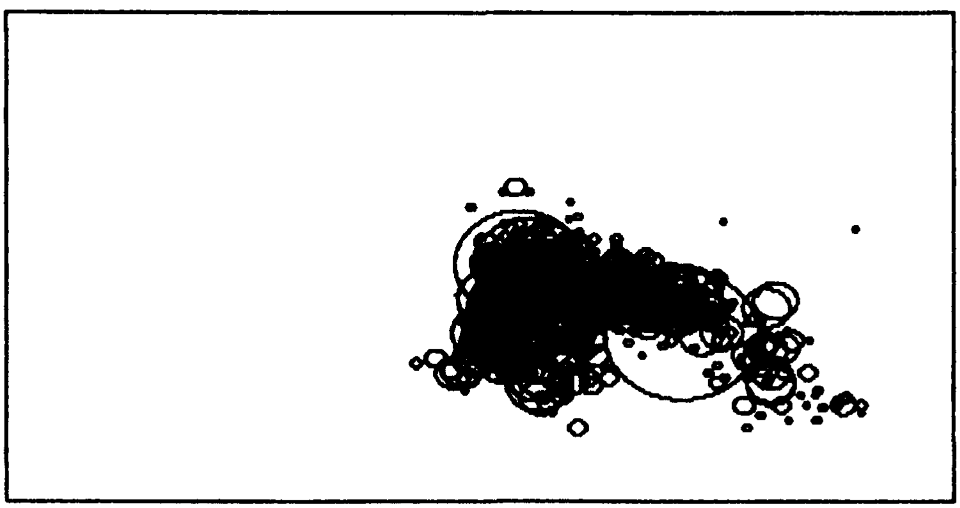

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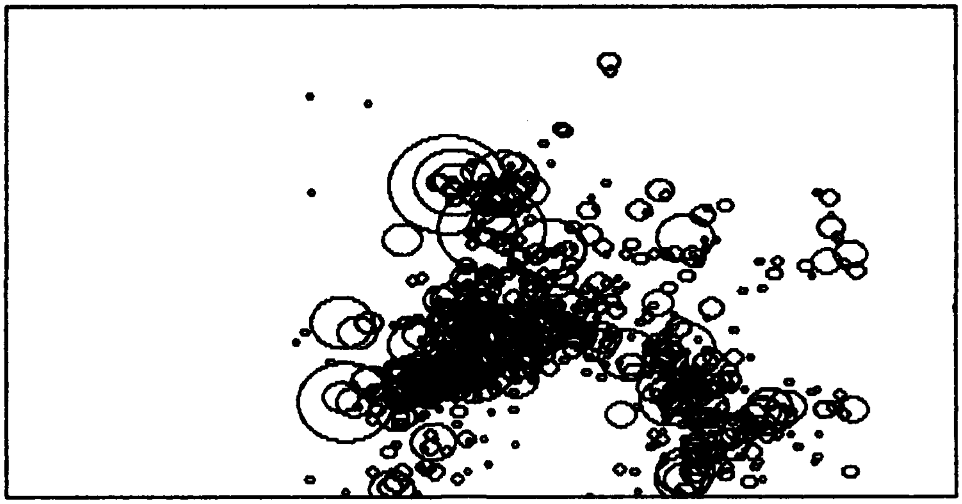

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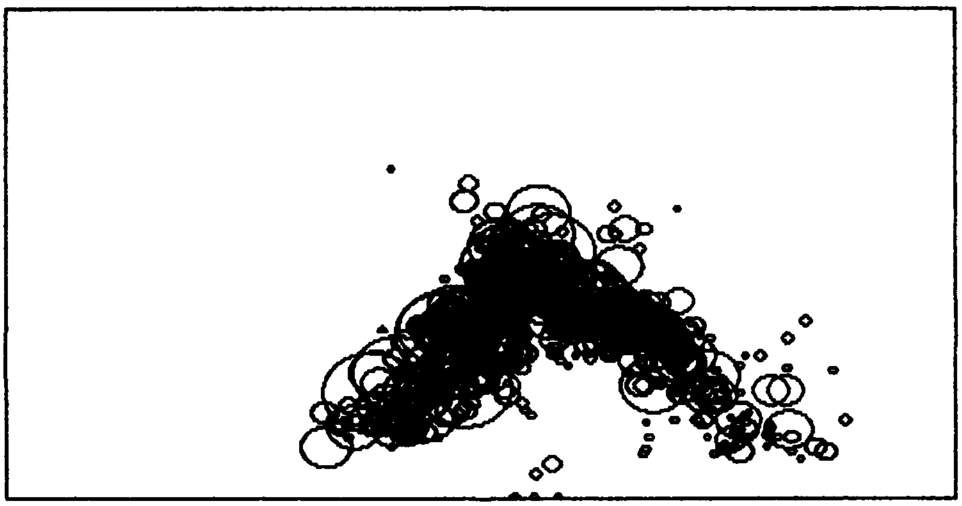

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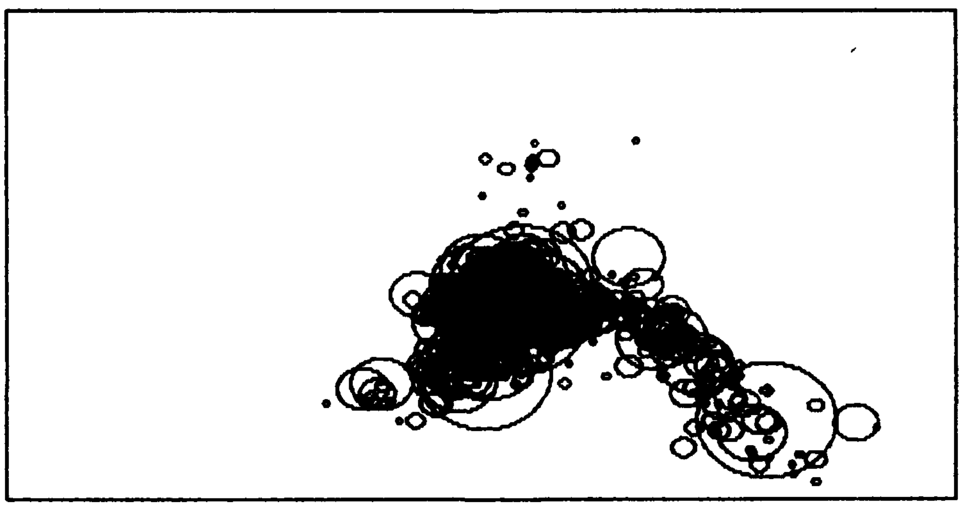

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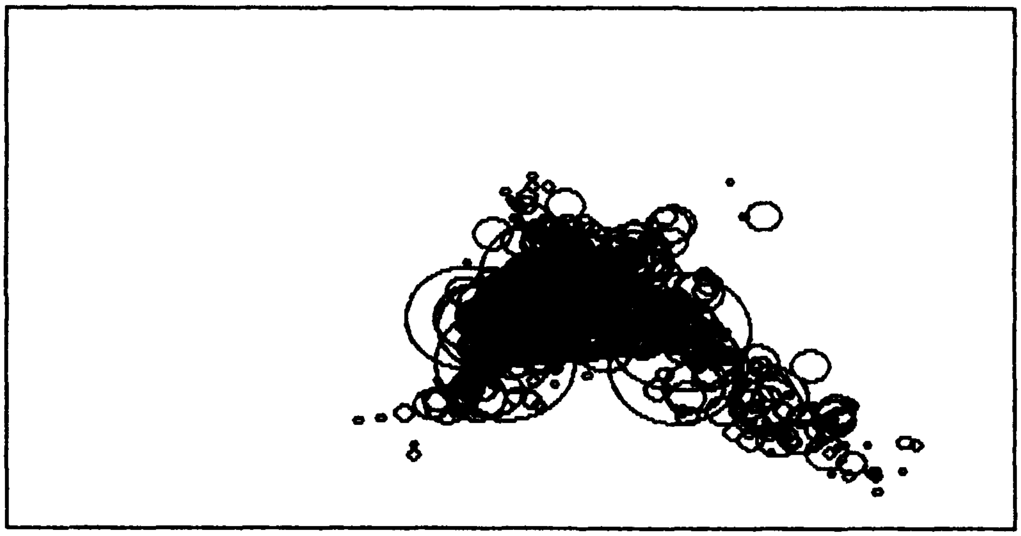

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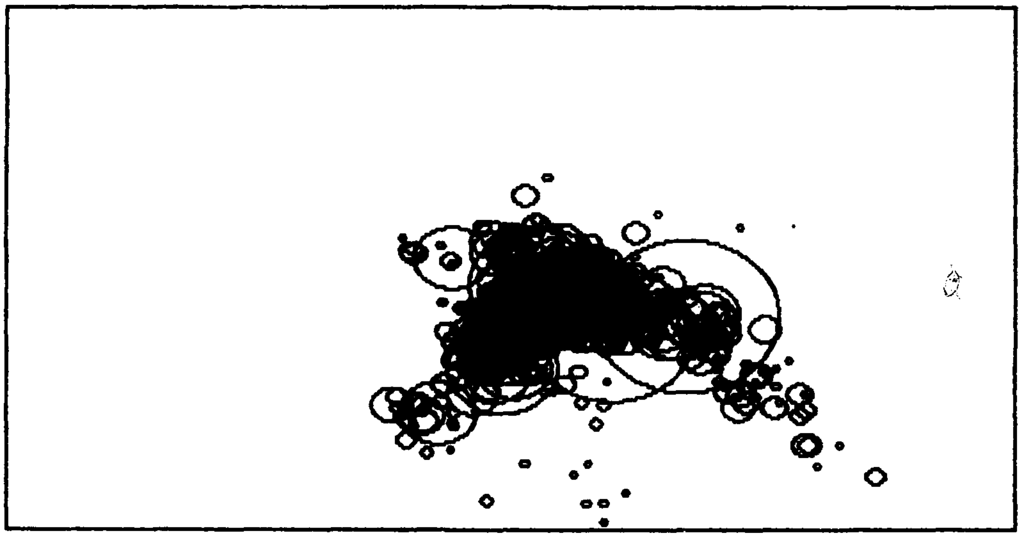

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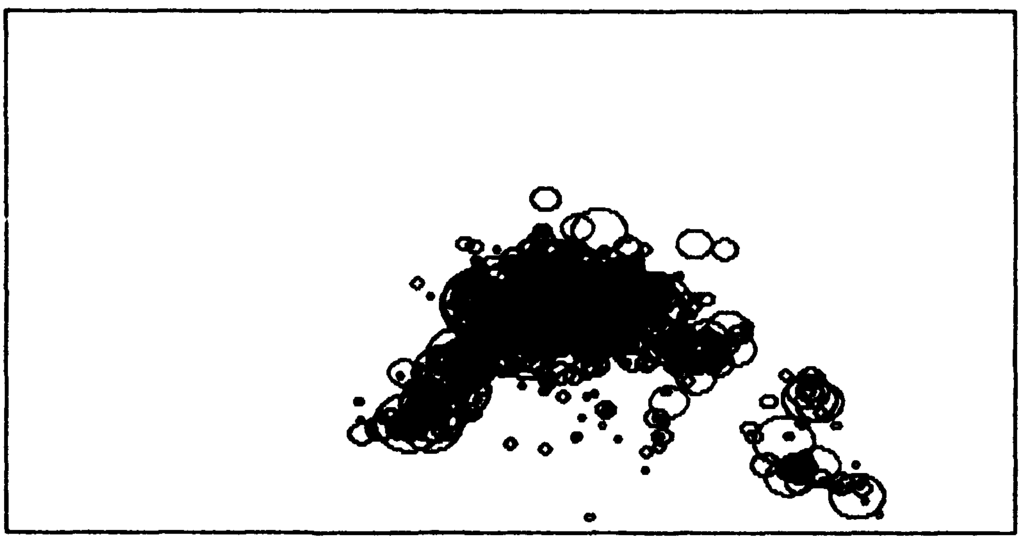
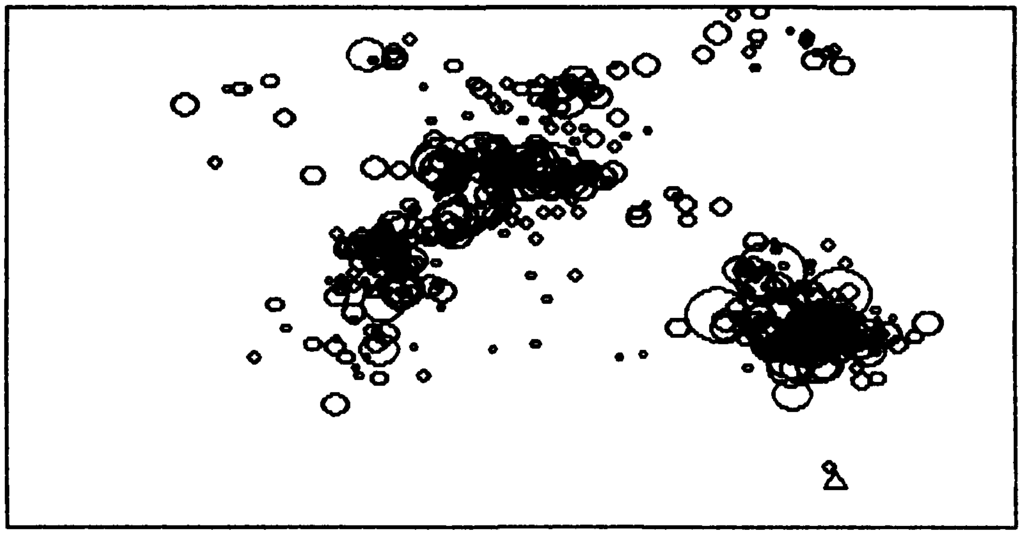


PARTICIPANT 05 RUN 22, 0-5 MINS L LOAD 9/13/90



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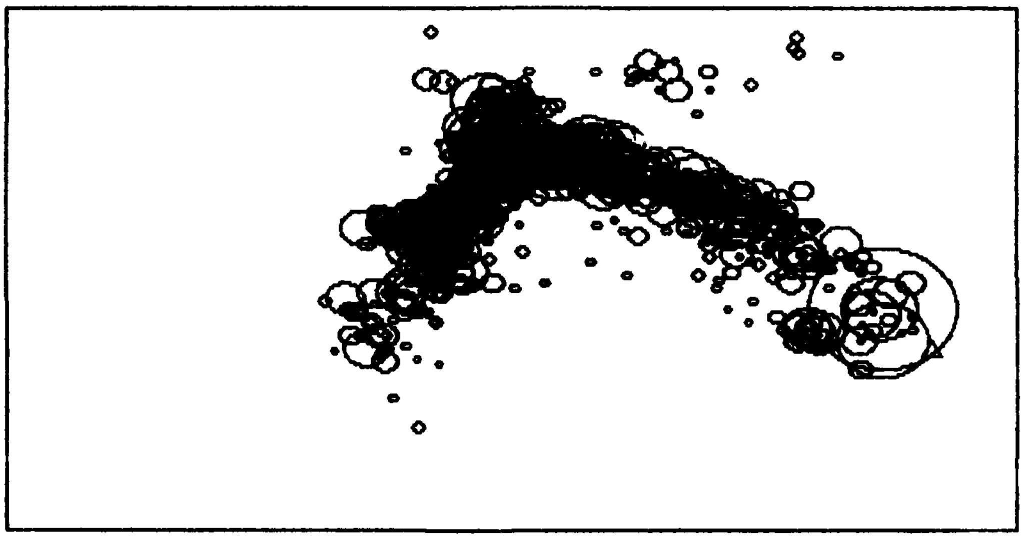
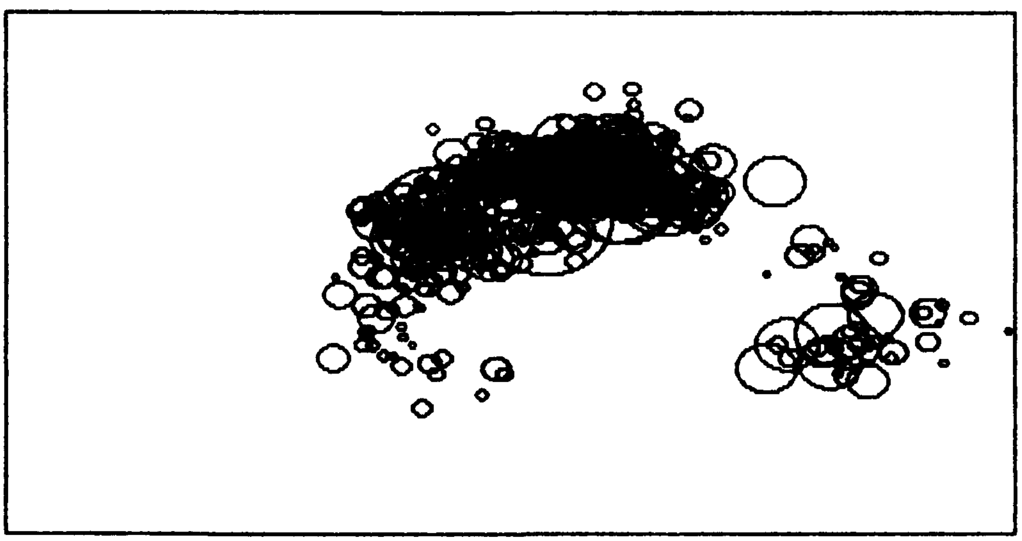
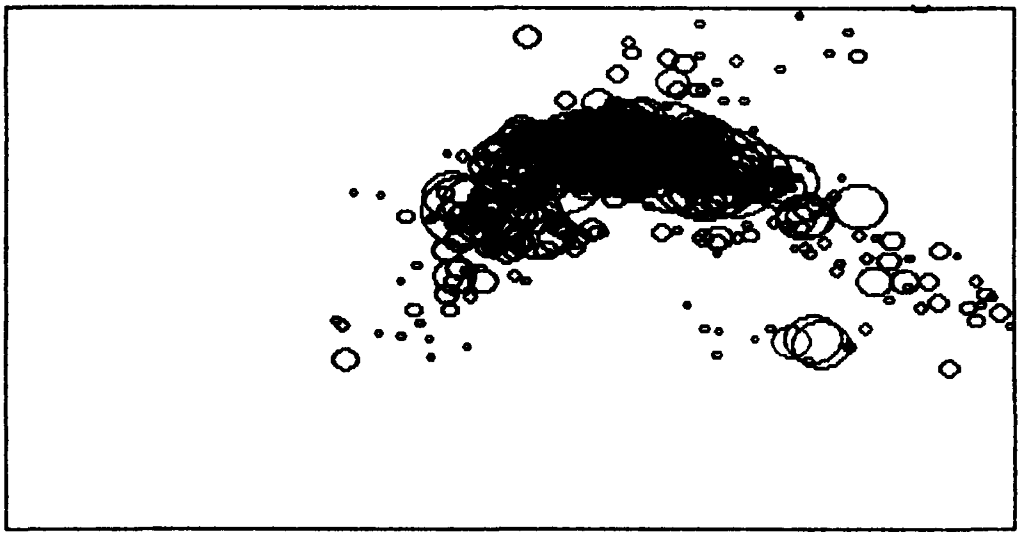


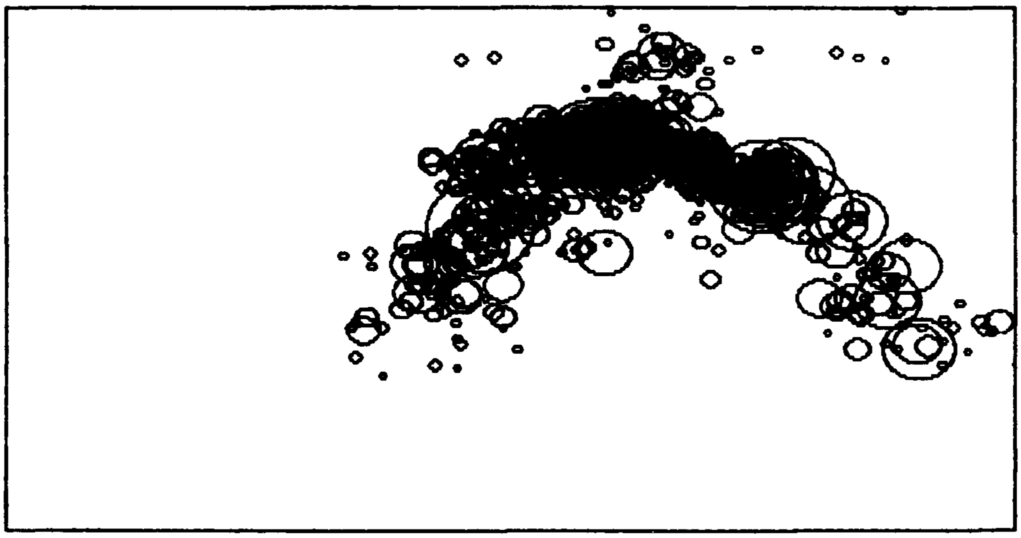
PARTICIPANT 05 RUN 22, 10-15 MINS L LOAD 9/13/90



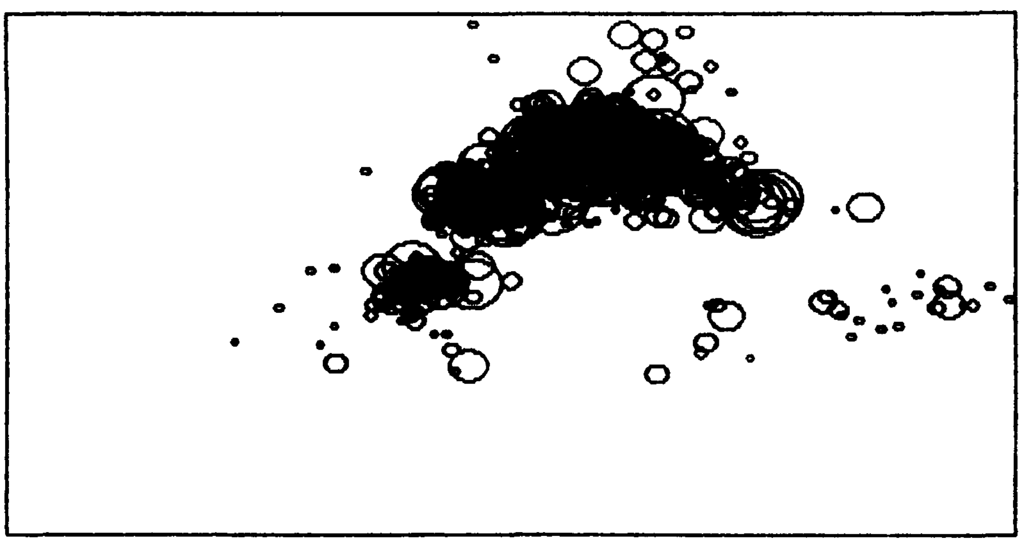
PARTICIPANT 05 RUN 22, 15-20 MINS L LOAD 9/13/90



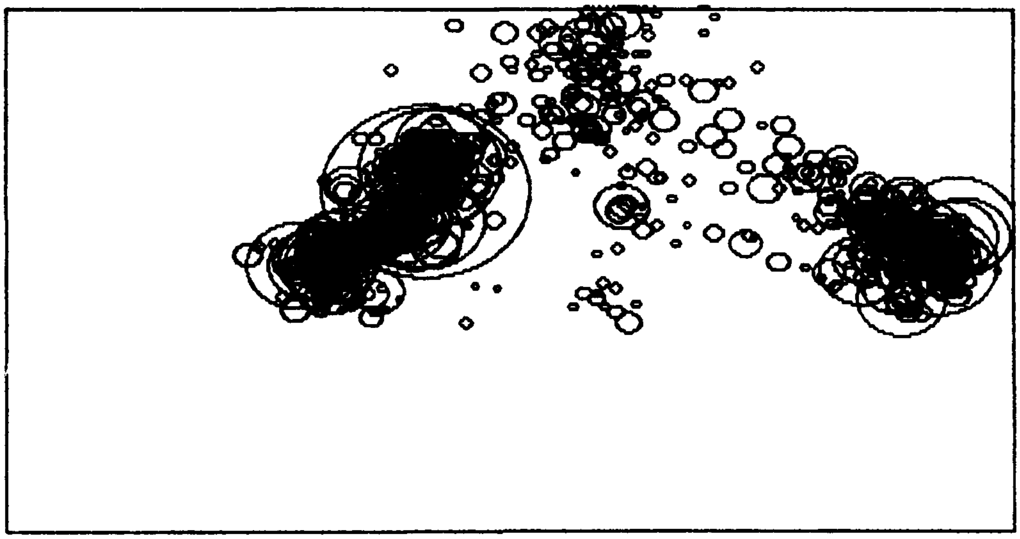
PARTICIPANT 05 RUN 22, 20-25 MINS L LOAD 9/13/90



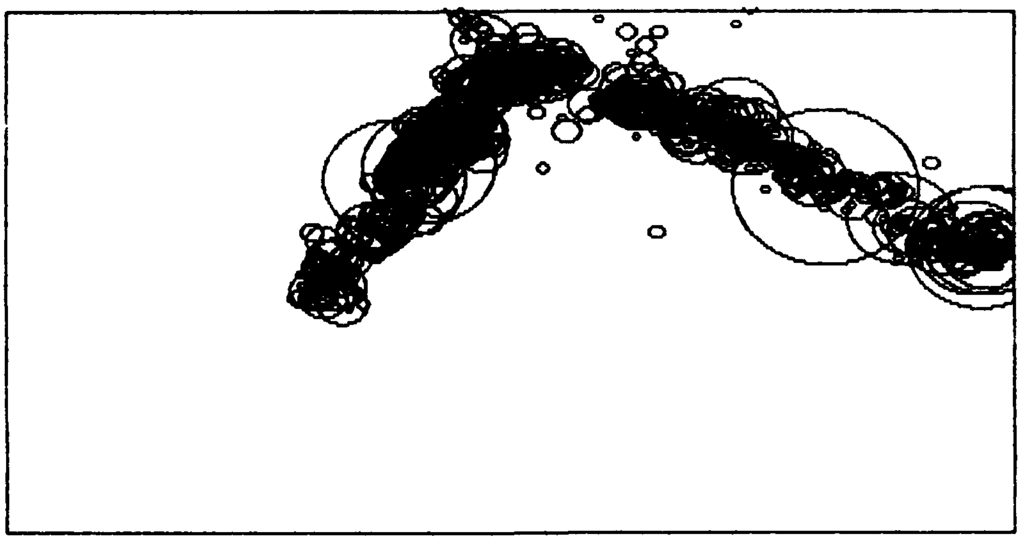
PARTICIPANT 05 RUN 22, 25-30 MINS L LOAD 9/13/90



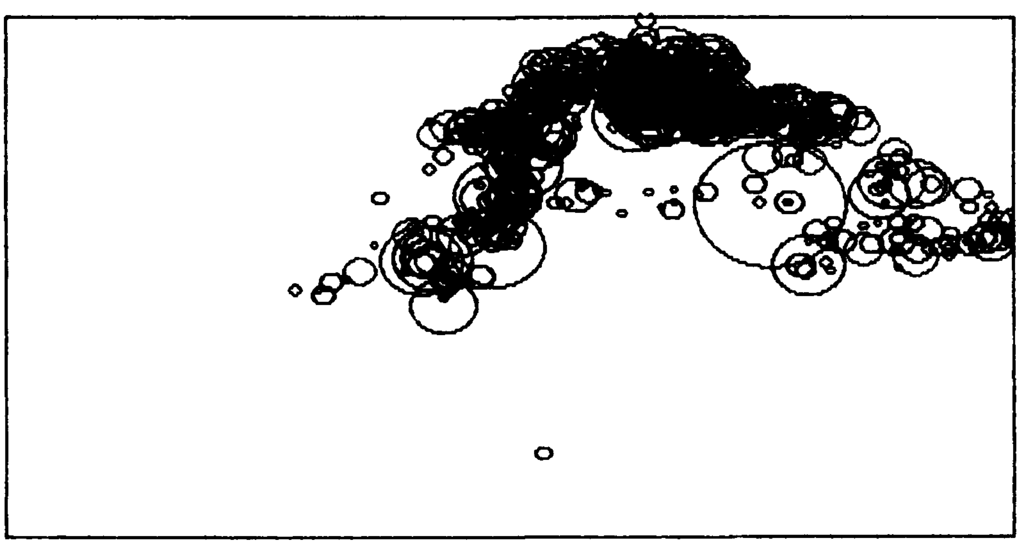
PARTICIPANT 05 RUN 23, 0-5 MINS H LOAD 9/13/90



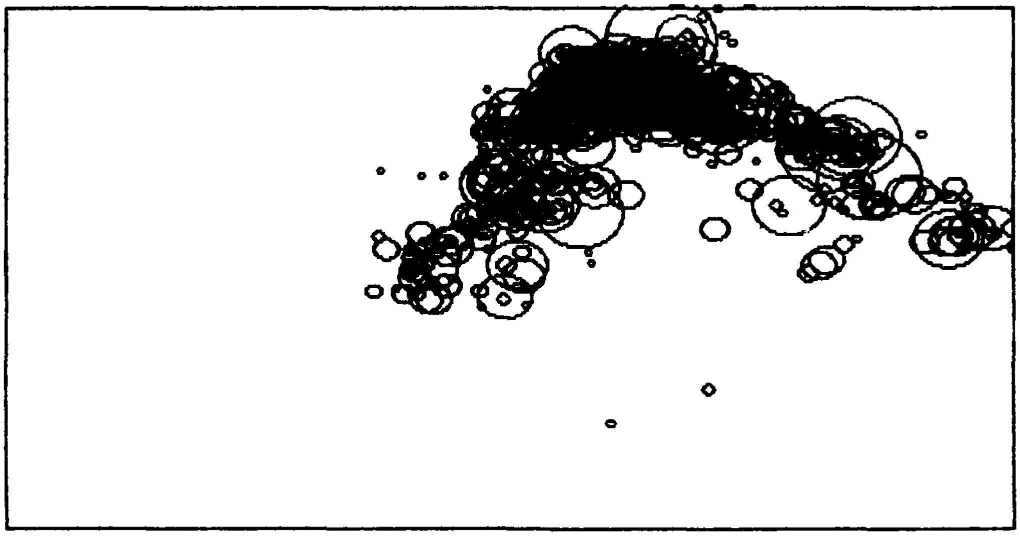
PARTICIPANT 05 RUN 23, 5-10 MINS H LOAD 9/13/90



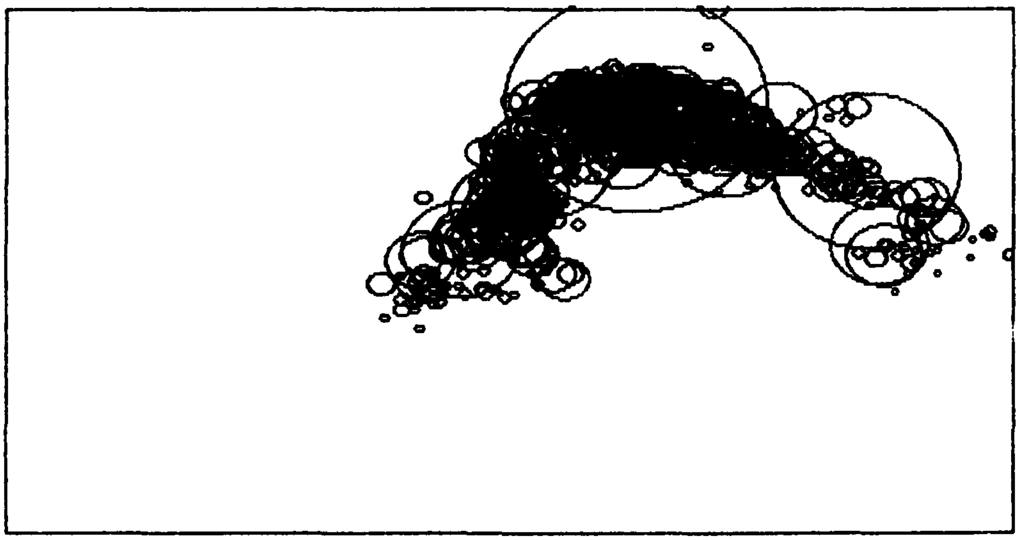
PARTICIPANT 05 RUN 23, 10-15 MINS H LOAD 9/13/90



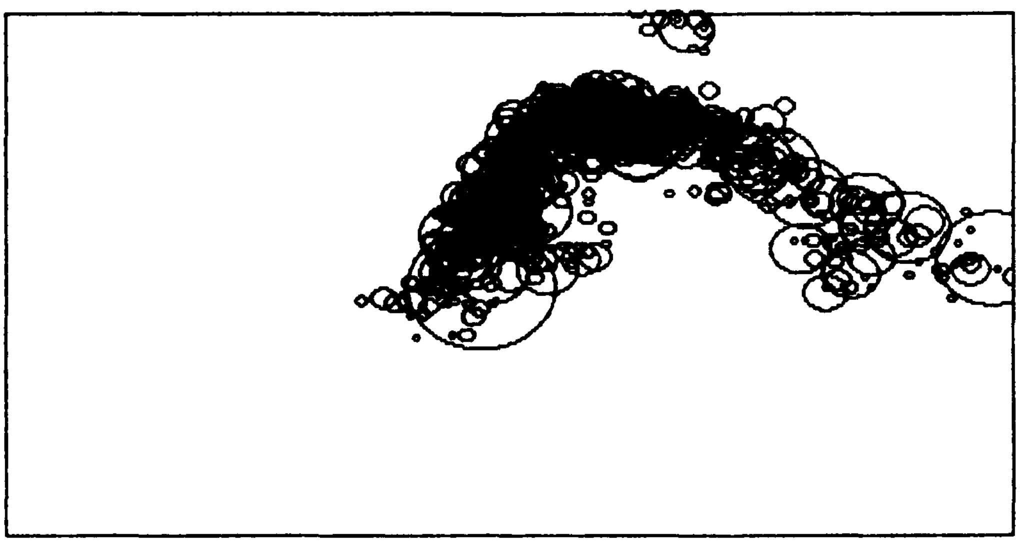
PARTICIPANT 05 RUN 23, 15-20 MINS H LOAD 9/13/90



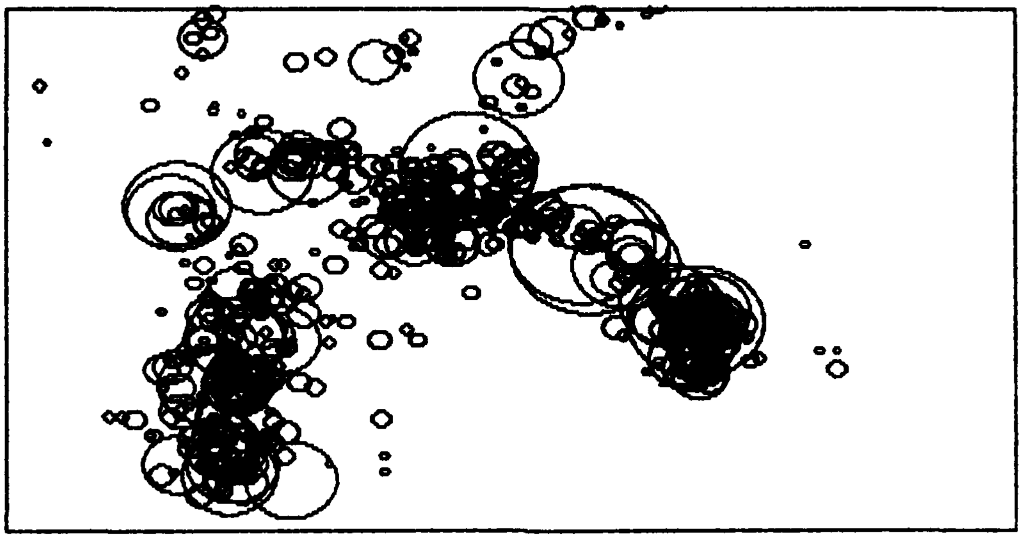
PARTICIPANT 05 RUN 23, 20-25 MINS H LOAD 9/13/90



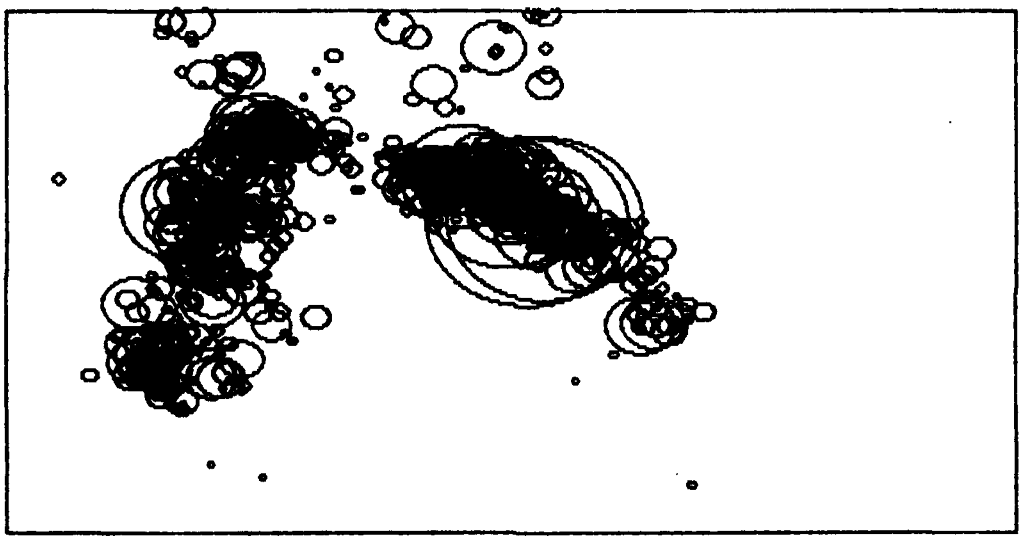
PARTICIPANT 05 RUN 23, 25-30 MINS H LOAD 9/13/90



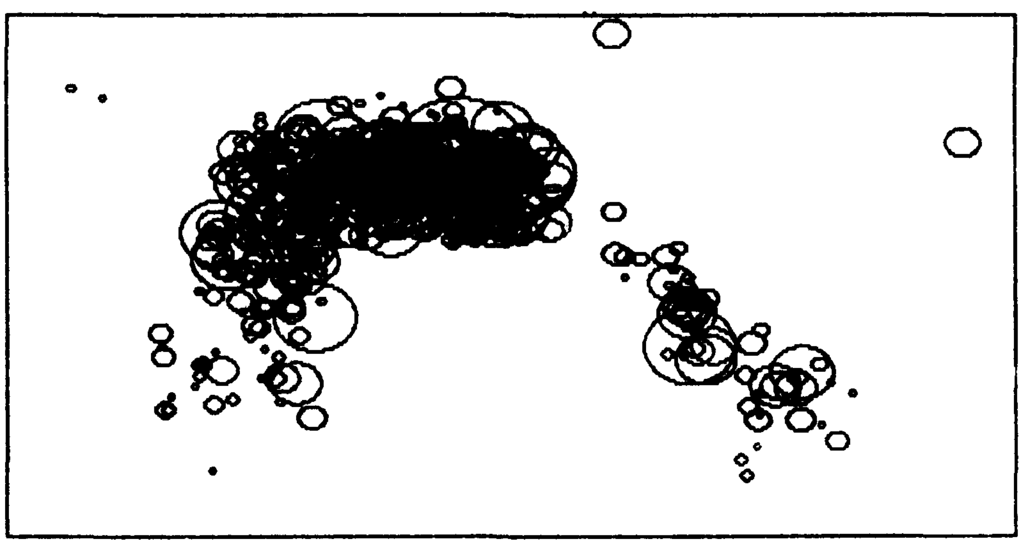
PARTICIPANT 07 RUN 31, 0-5 MINS L LOAD 1/8/91



PARTICIPANT 07 RUN 31, 5-10 MINS L LOAD 1/8/91



PARTICIPANT 07 RUN 31, 10-15 MINS L LOAD 1/8/91



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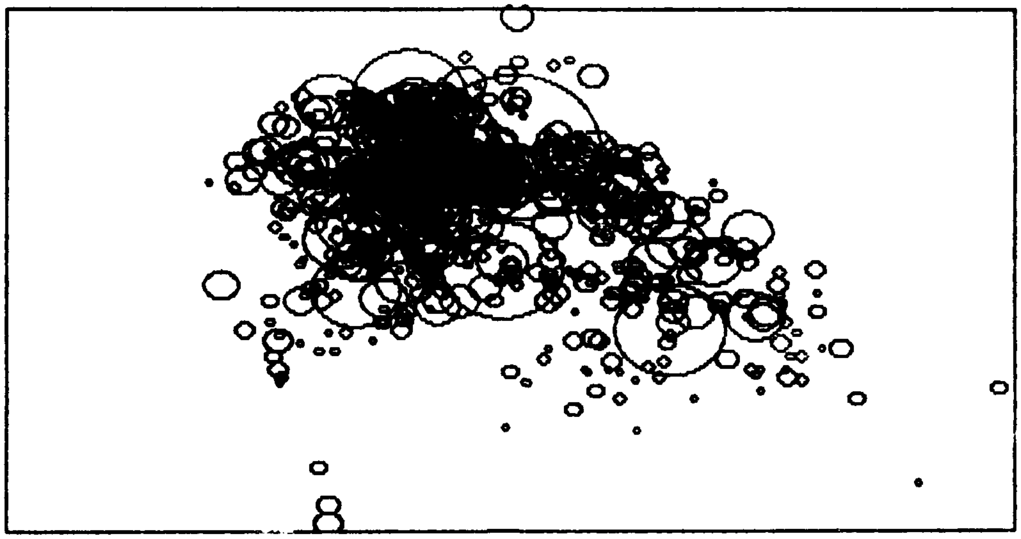
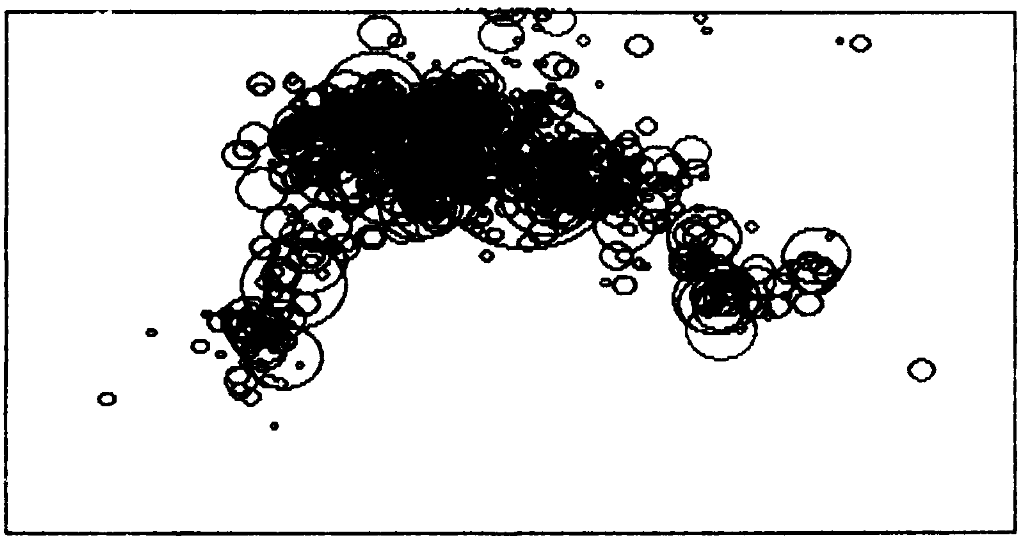
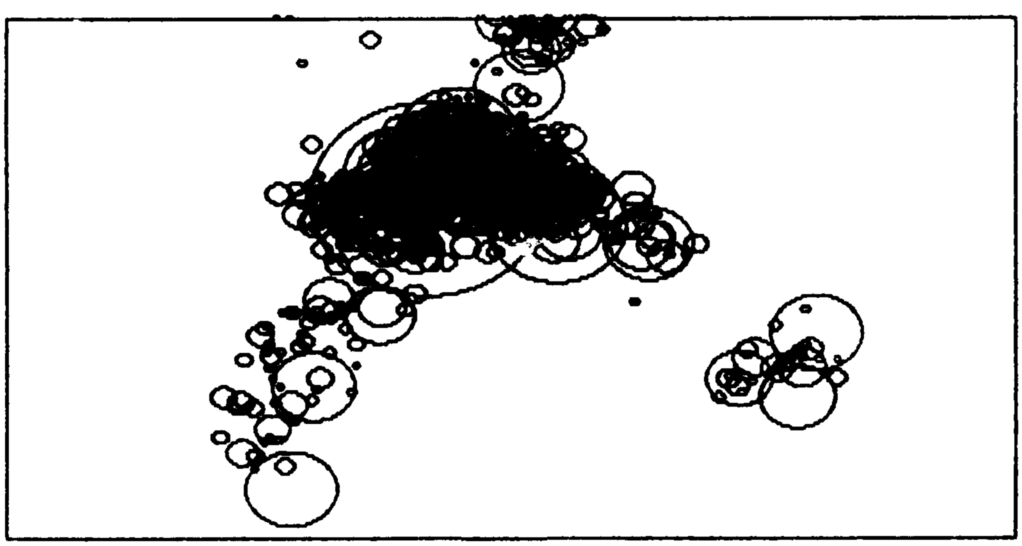


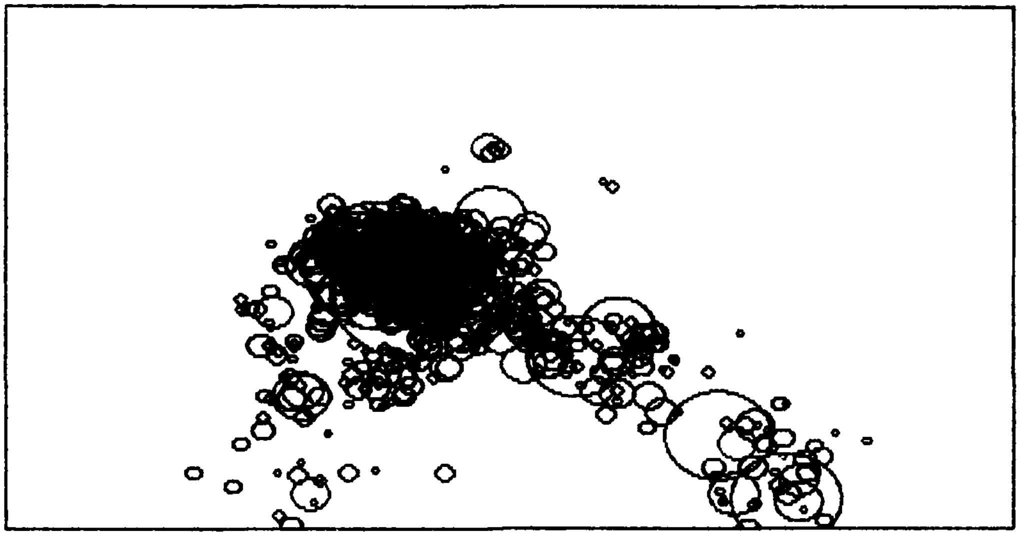
PARTICIPANT 07 RUN 31, 20-25 MINS L LOAD 1/8/91



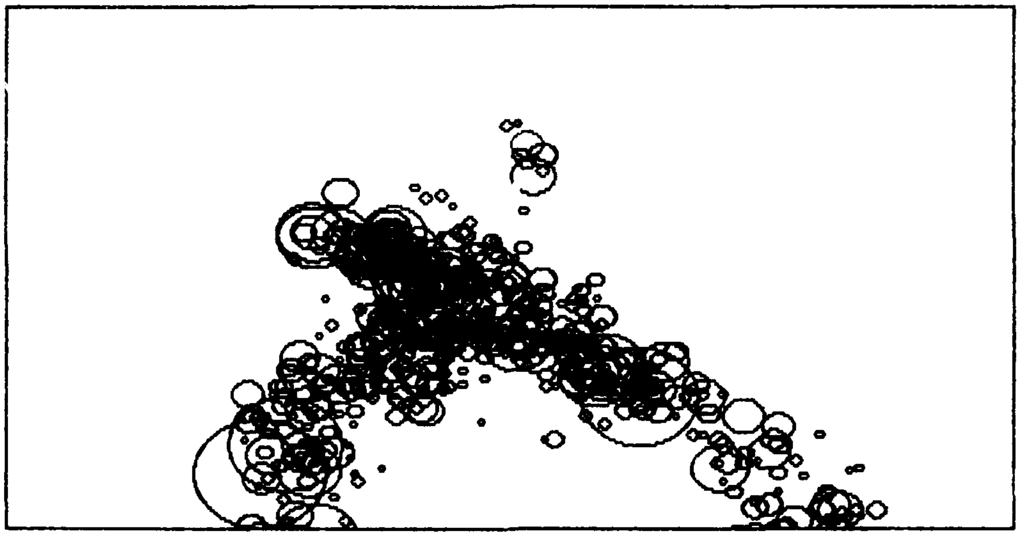
PARTICIPANT 07 RUN 3 , 25-30 MINS L LOAD 1/8/91



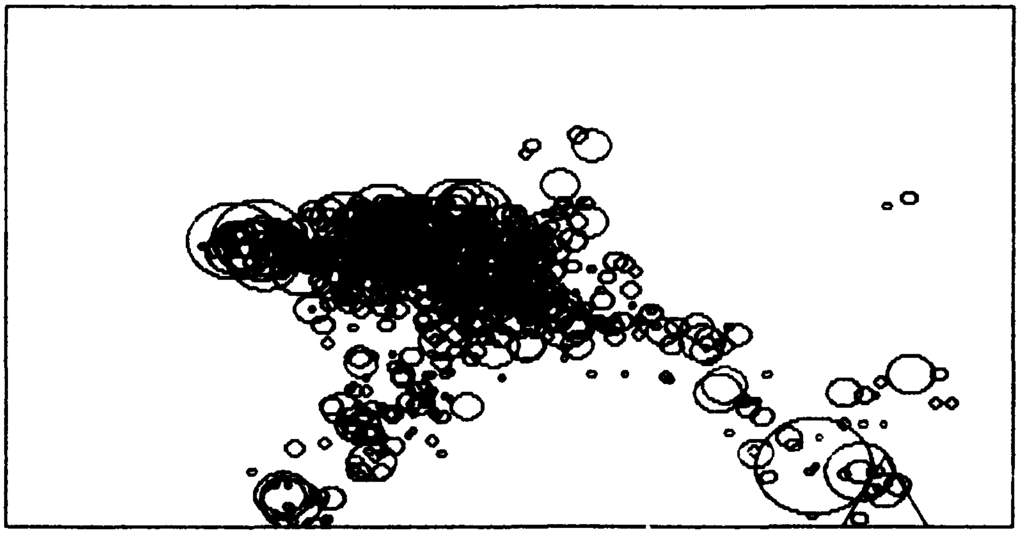
PARTICIPANT 07 RUN 34, 15-20 MINS H LOAD 1/8/91



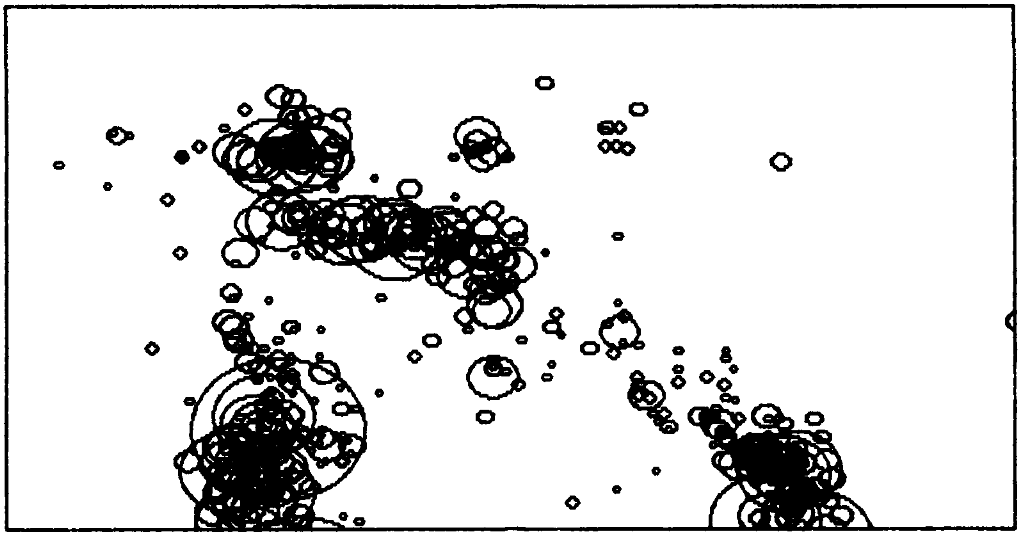
PARTICIPANT 07 RUN 34, 20-25 MINS H LOAD 1/8/91



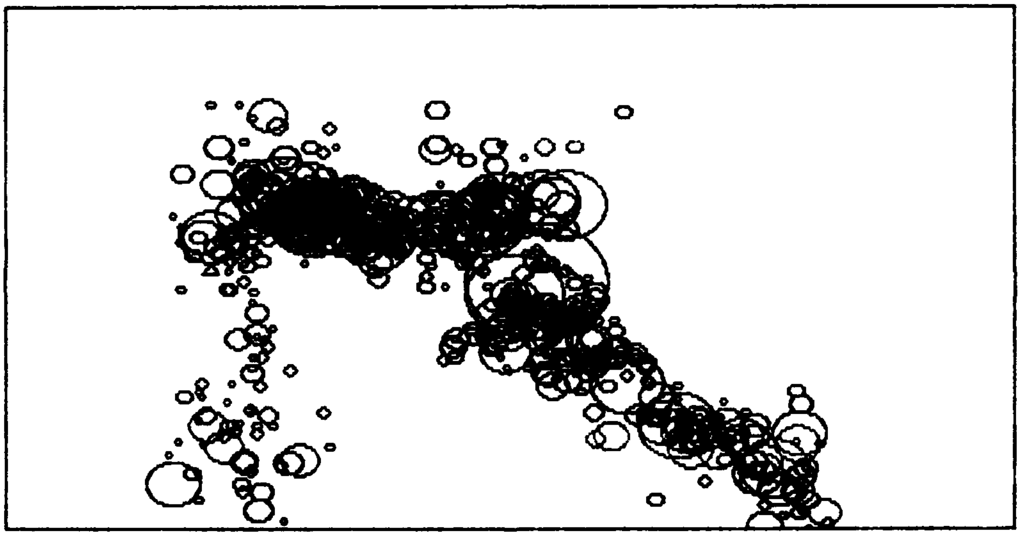
PARTICIPANT 07 RUN 34, 25-30 MINS H LOAD 1/8/91



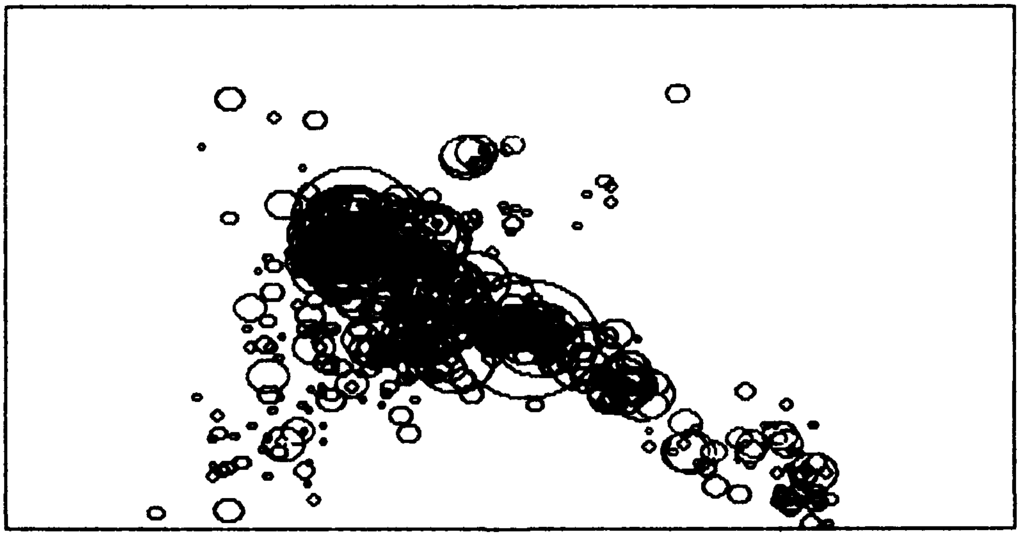
PARTICIPANT 07 RUN 34, 0-5 MINS H LOAD 1/8/91



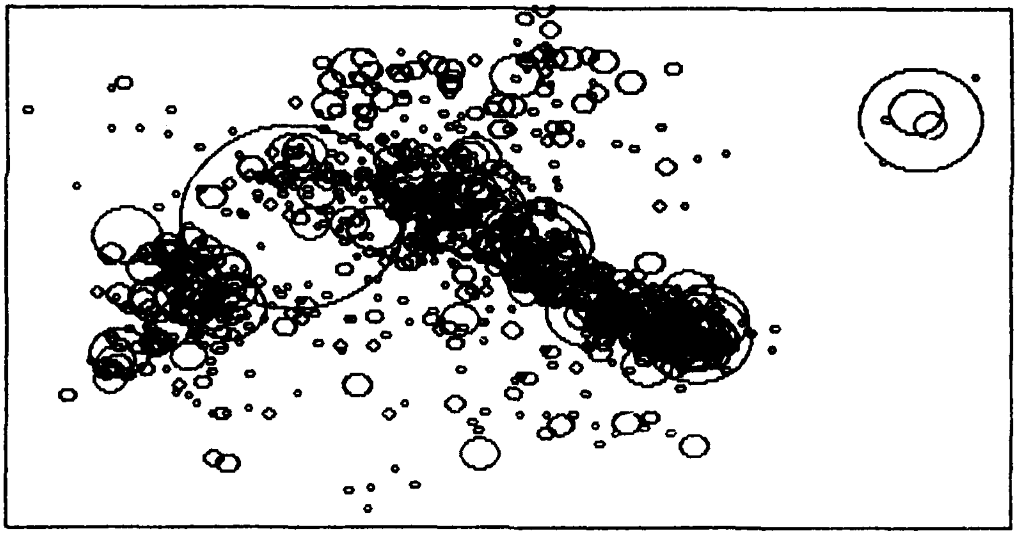
PARTICIPANT 07 RUN 34, 5-10 MINS H LOAD 1/8/91



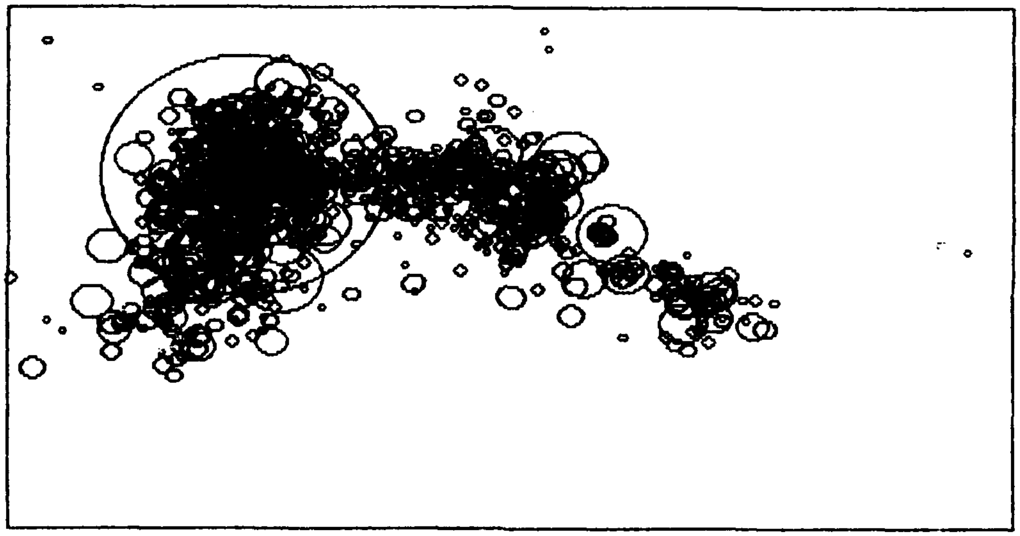
PARTICIPANT 07 RUN 34, 10-15 MINS H LOAD 1/8/91



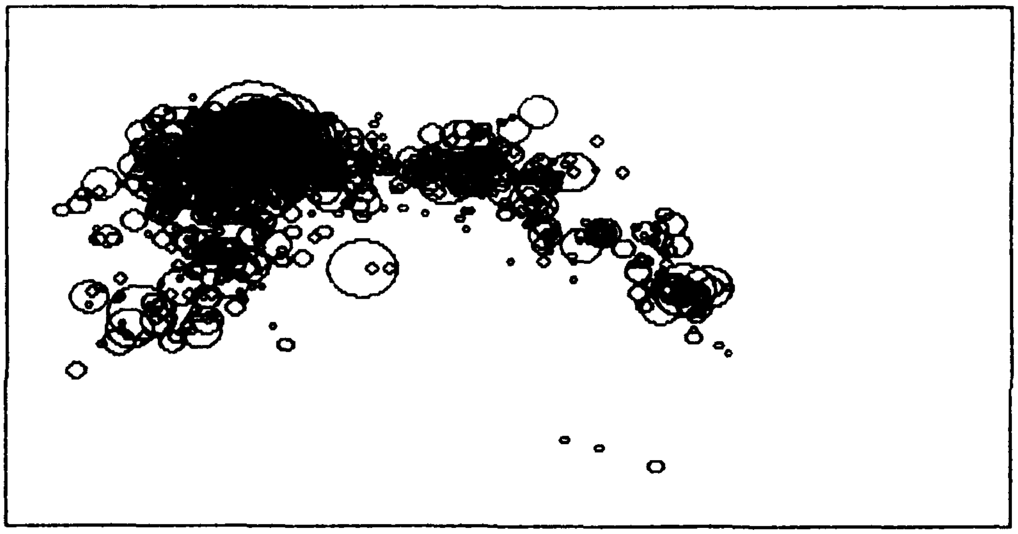
PARTICIPANT 08 RUN 32, 0-5 MINS H LOAD 1/8/91



PARTICIPANT 08 RUN 32, 5-10 MINS H LOAD 1/8/91



PARTICIPANT 08 RUN 32, 10-15 MINS H LOAD 1/8/91



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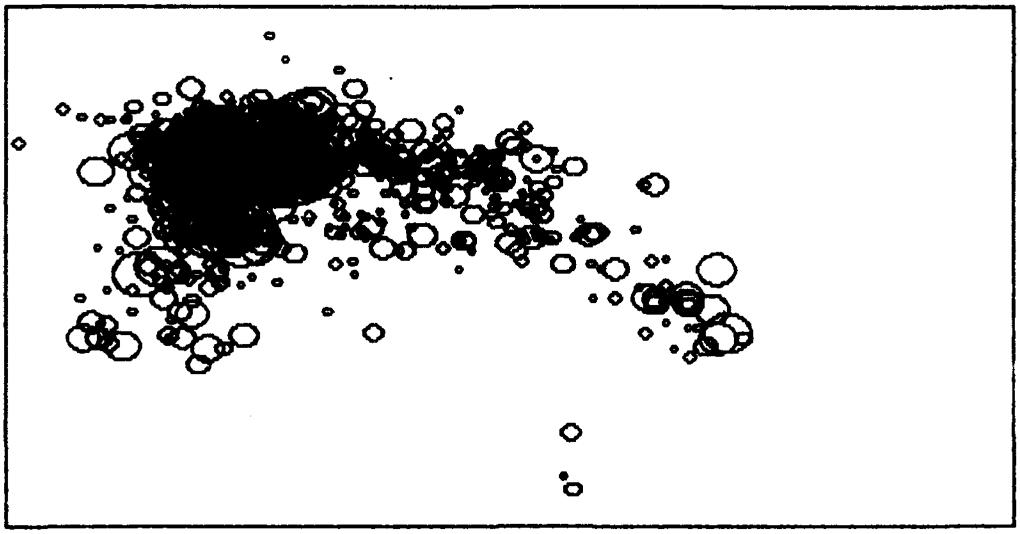

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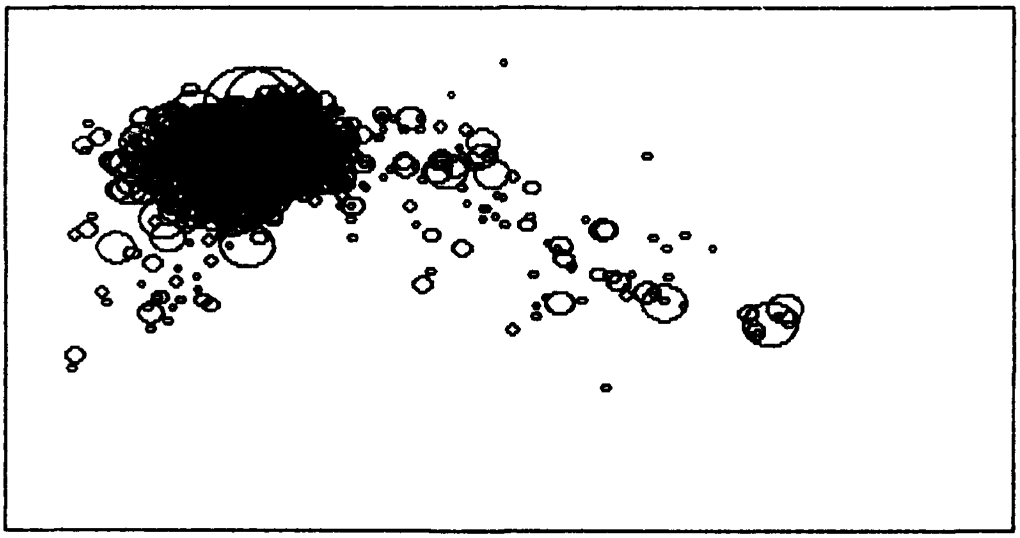
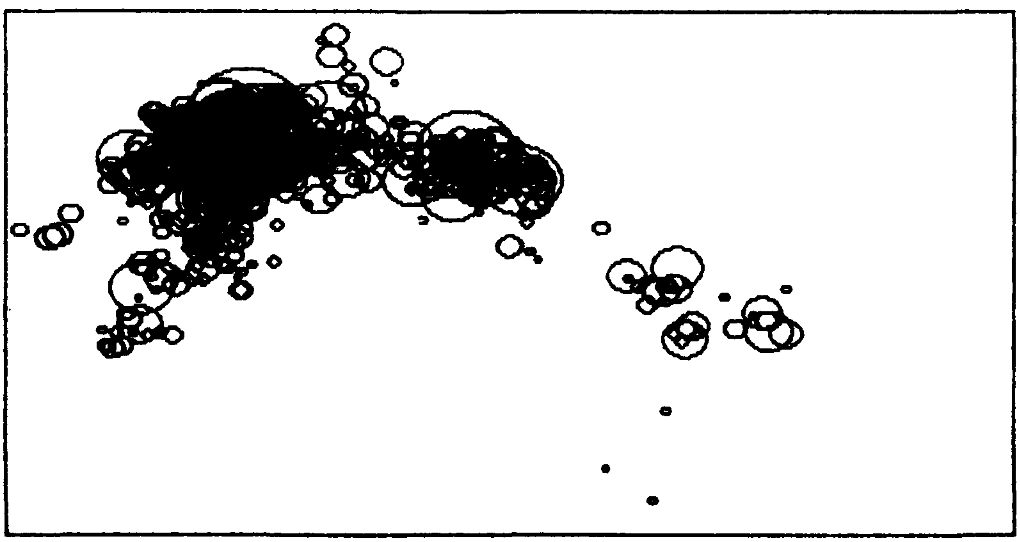
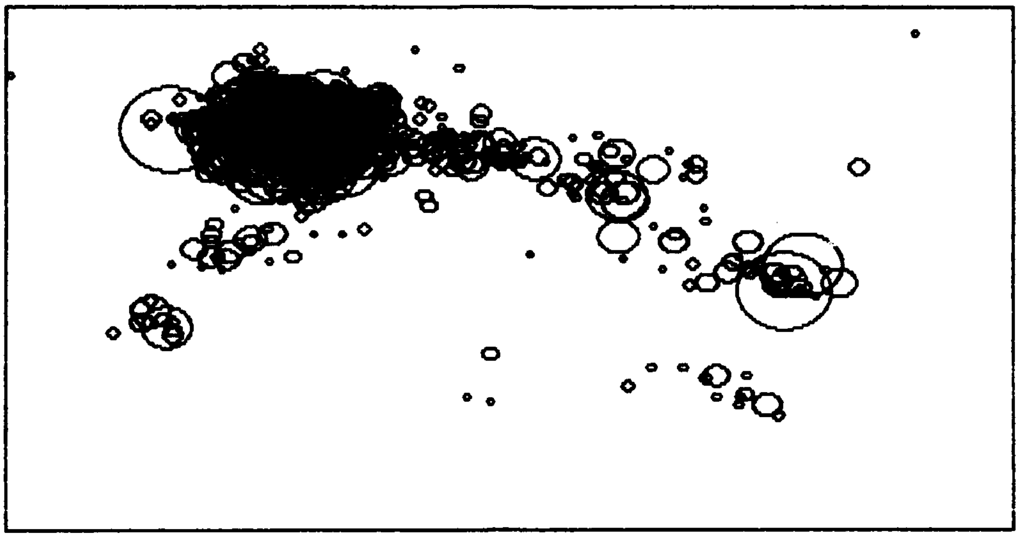


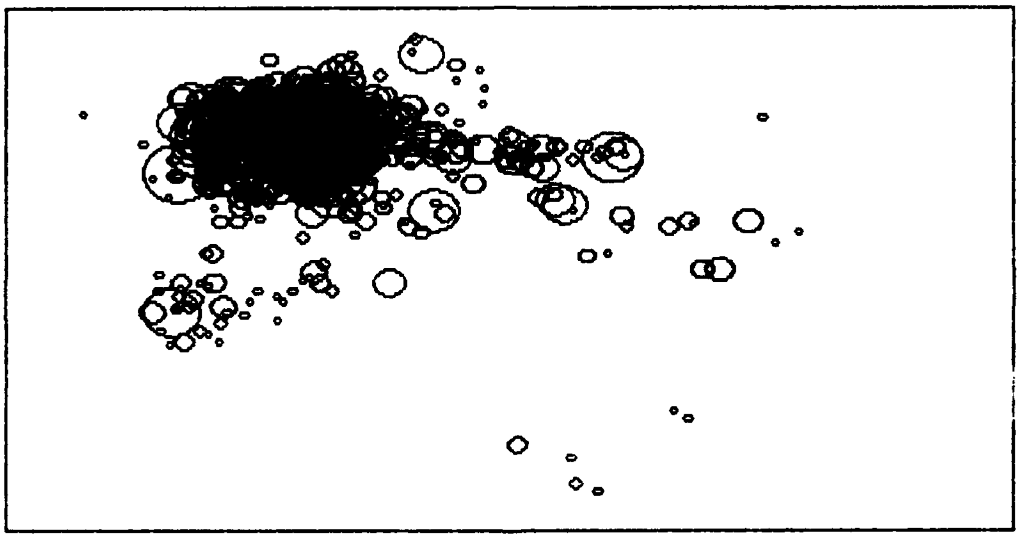
PARTICIPANT 08 RUN 32, 25-30 MINS H LOAD 1/8/91



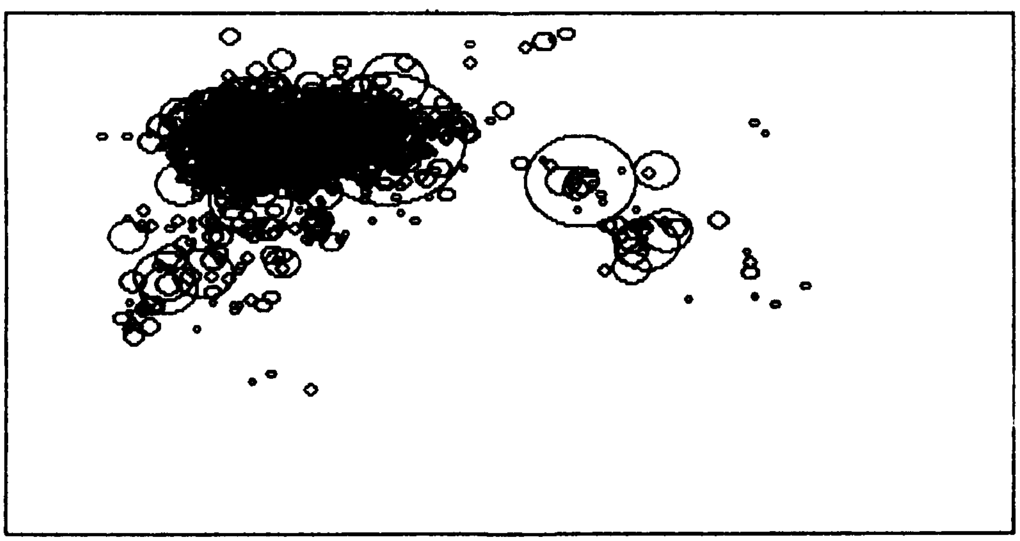
PARTICIPANT 08 RUN 33, 15-20 MINS L LOAD 1/8/91



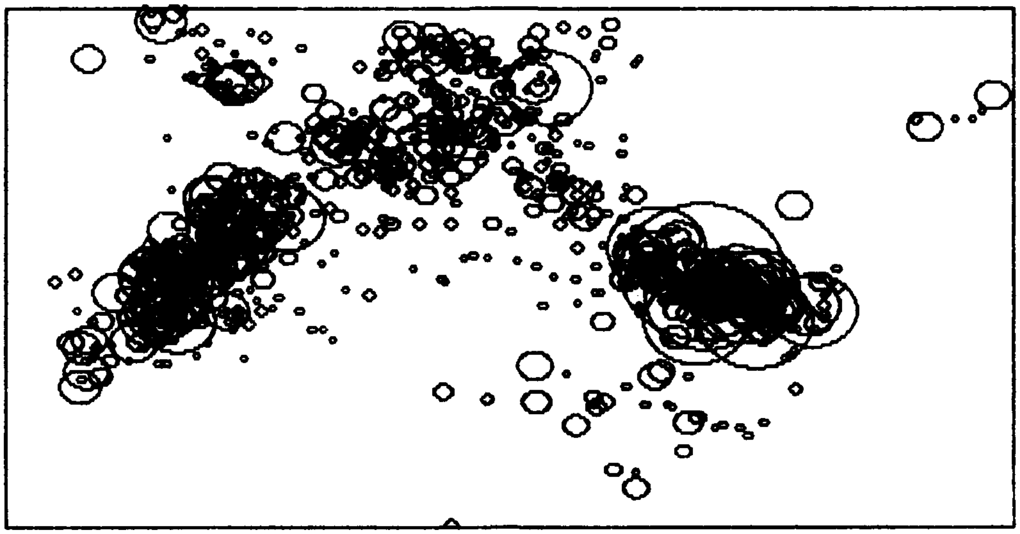
PARTICIPANT 08 RUN 33, 20-25 MINS L LOAD 1/8/91



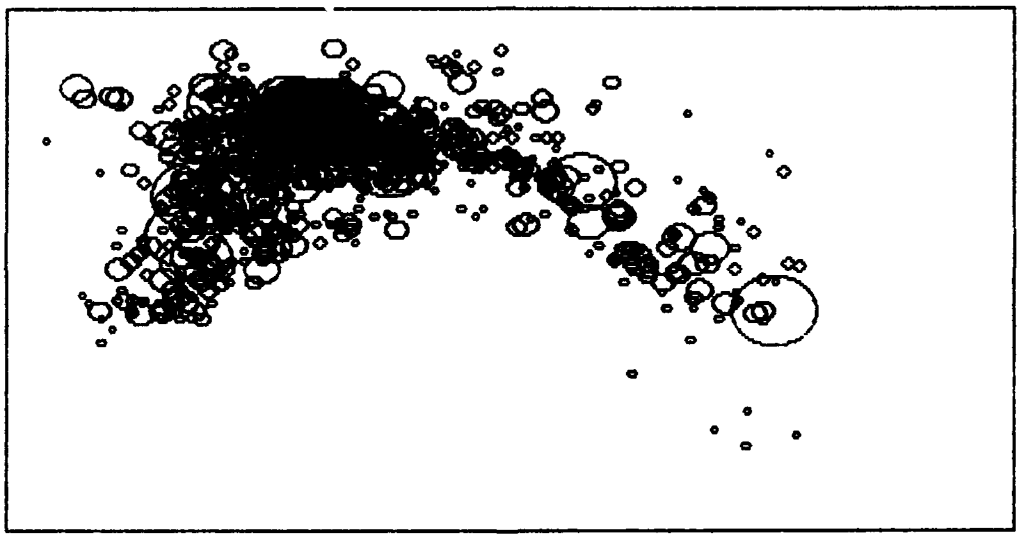
PARTICIPANT 08 RUN 33, 25-30 MINS L LOAD 1/8/91



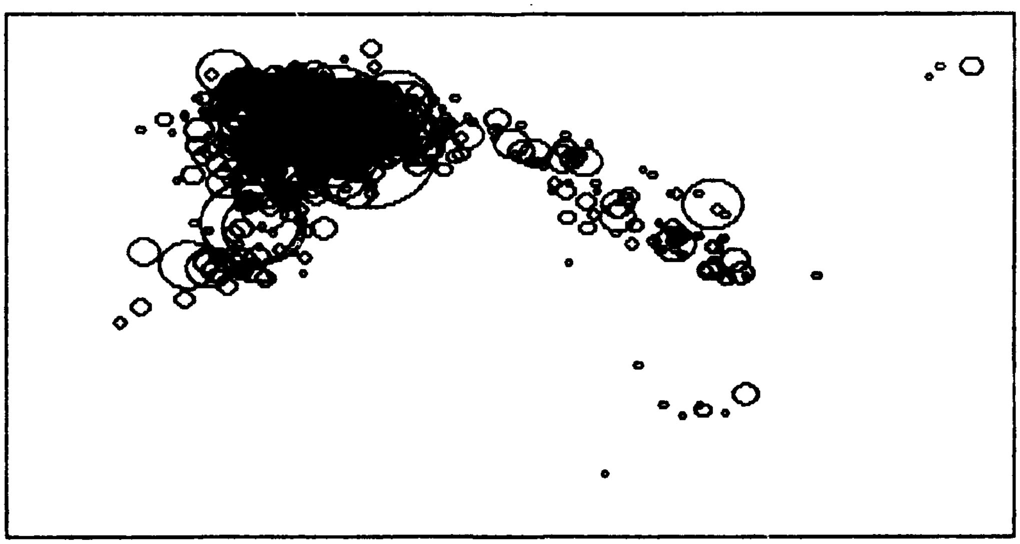
PARTICIPANT 08 RUN 33, 0-5 MINS L LOAD 1/8/91



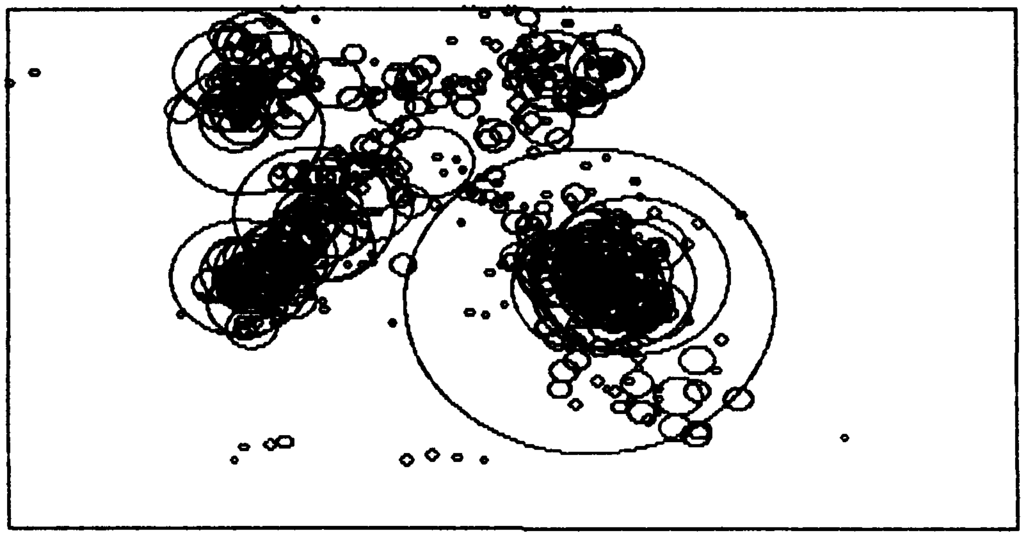
PARTICIPANT 08 RUN 33, 5-10 MINS L LOAD 1/8/91



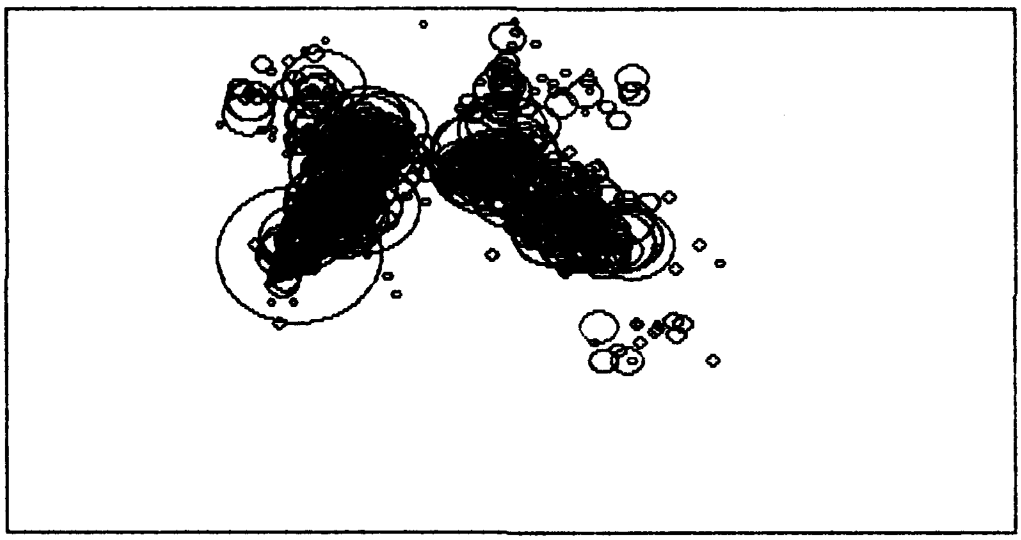
PARTICIPANT 08 RUN 33, 10-15 MINS L LOAD 1/8/91



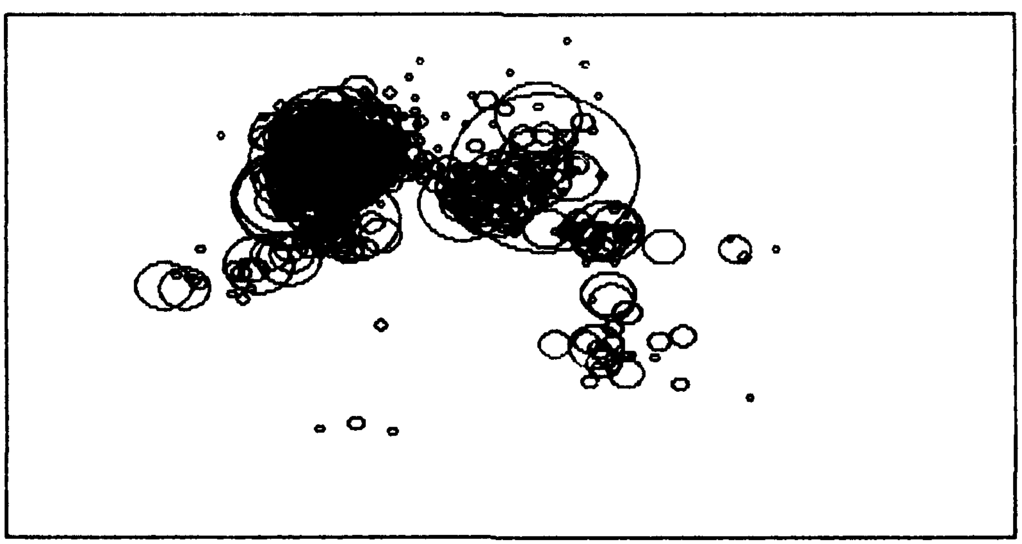
PARTICIPANT 10 RUN 42, 0-5 MINS L LOAD 1/10/91



PARTICIPANT 10 RUN 42, 5-10 MINS L LOAD 1/10/91



PARTICIPANT 10 RUN 42, 10-15 MINS L LOAD 1/10/91



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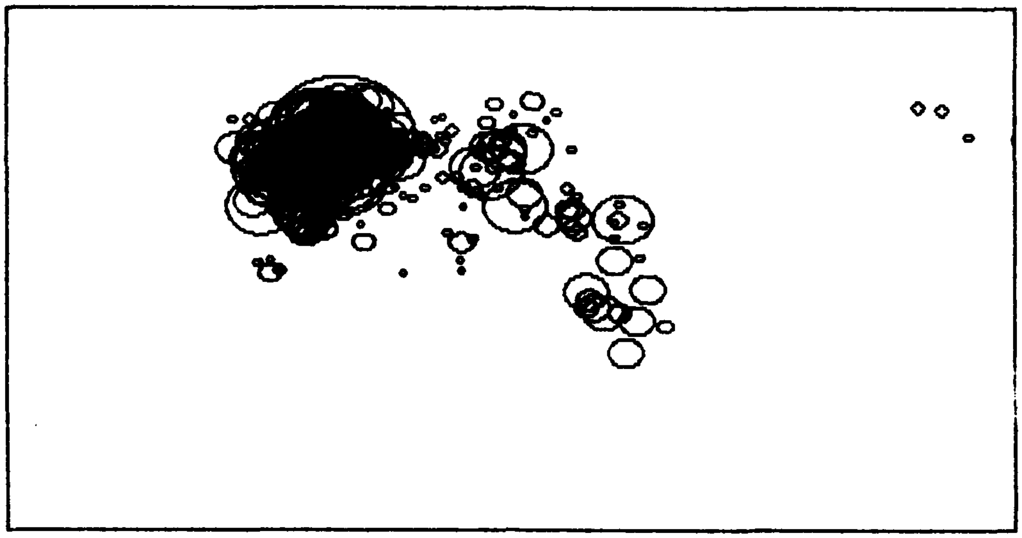
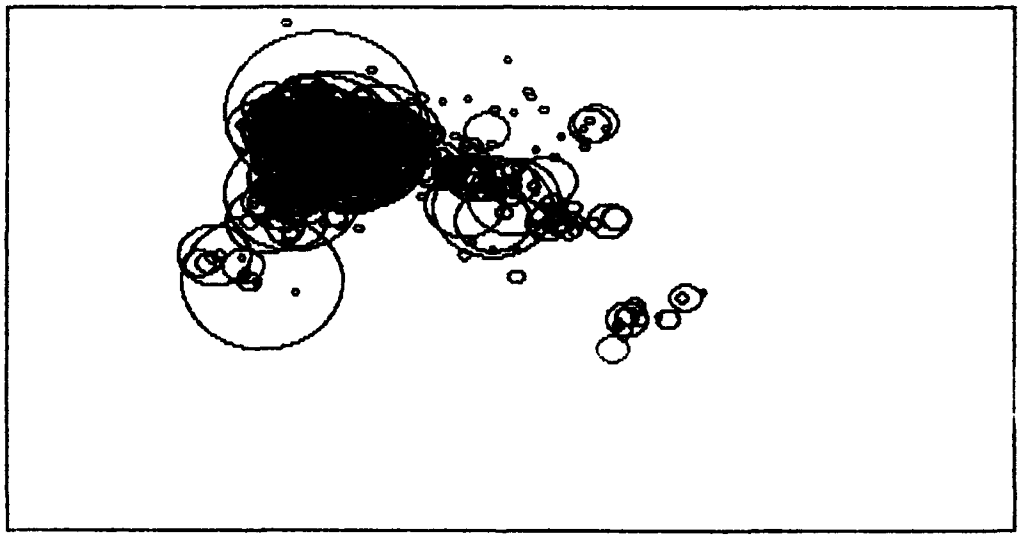
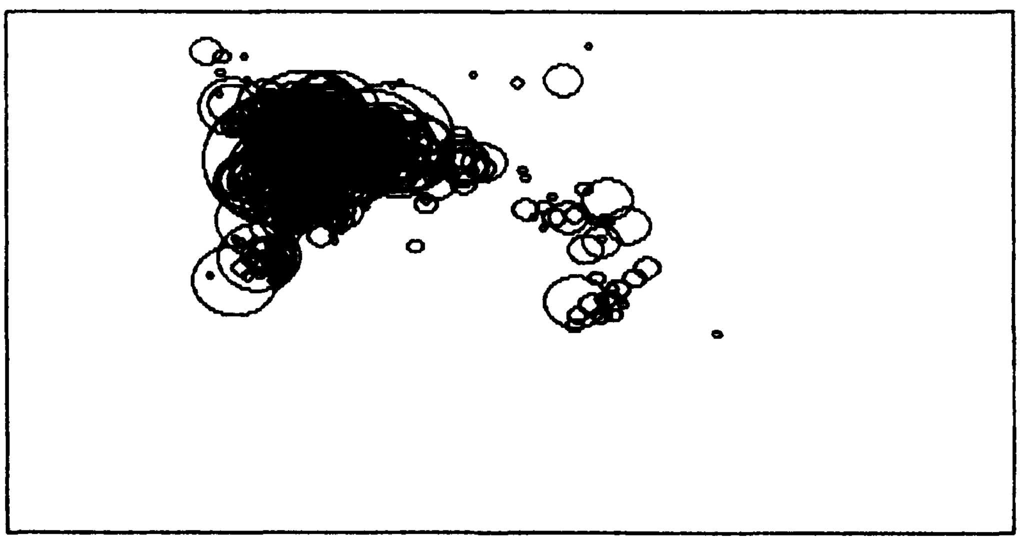


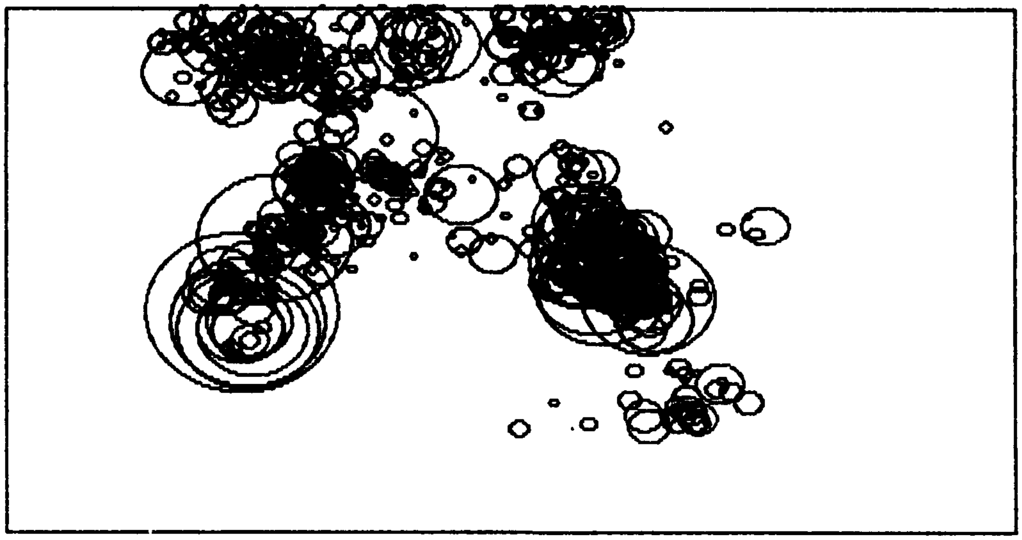
PARTICIPANT 10 RUN 42, 20-25 MINS L LOAD 1/10/91



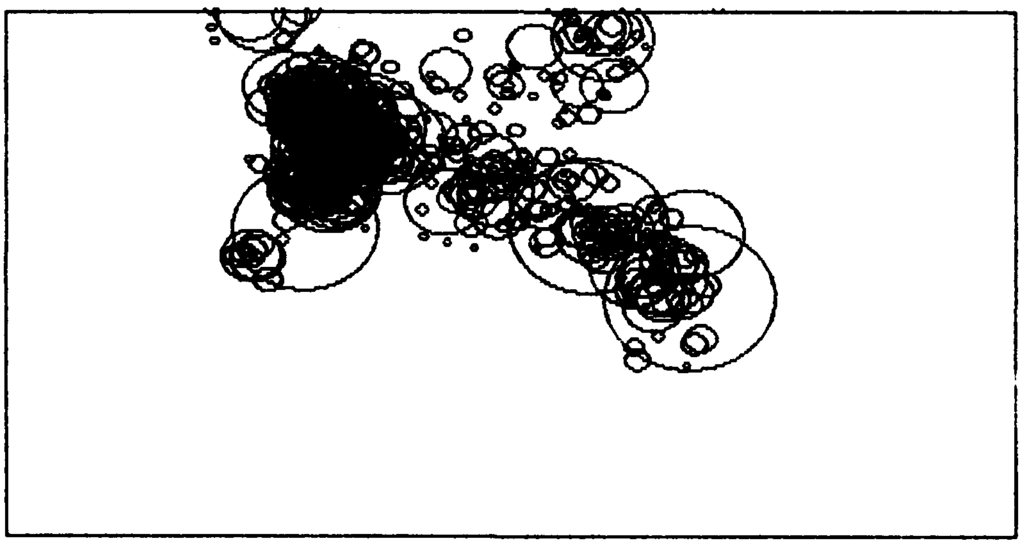
PARTICIPANT 10 RUN 42, 25-30 MINS L LOAD 1/10/91



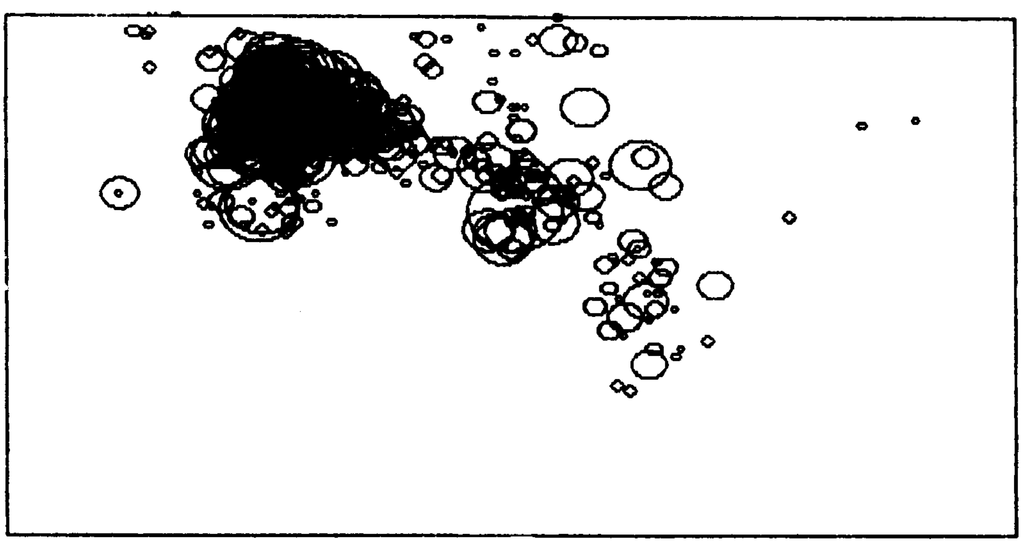
PARTICIPANT 10 RUN 43, 0-5 MINS H LOAD 1/10/91



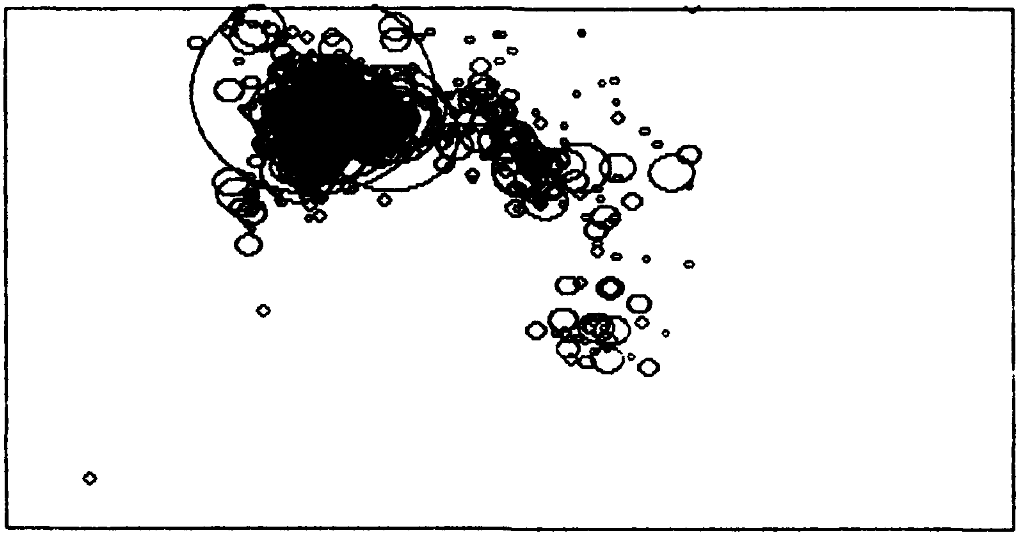
PARTICIPANT 10 RUN 43, 5-10 MINS H LOAD 1/10/91



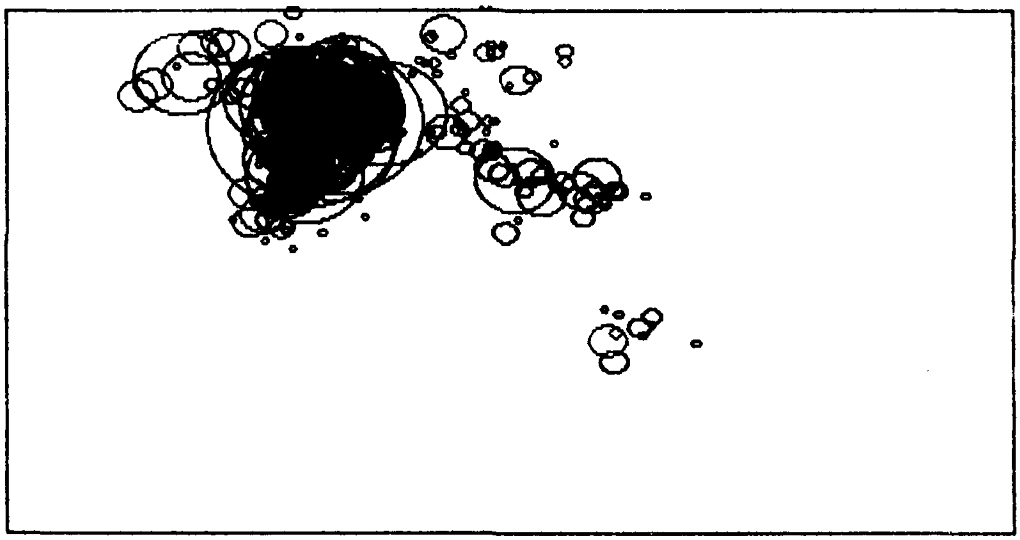
PARTICIPANT 10 RUN 43, 10-15 MINS H LOAD 1/10/91



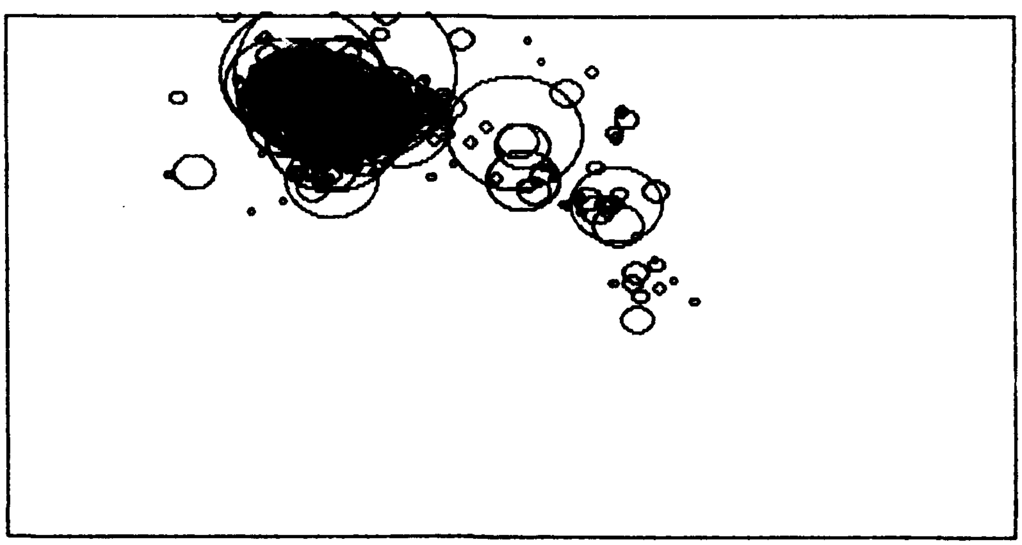
PARTICIPANT 10 RUN 43, 15-20 MINS H LOAD 1/10/91



PARTICIPANT 10 RUN 43, 20-25 MINS H LOAD 1/10/91

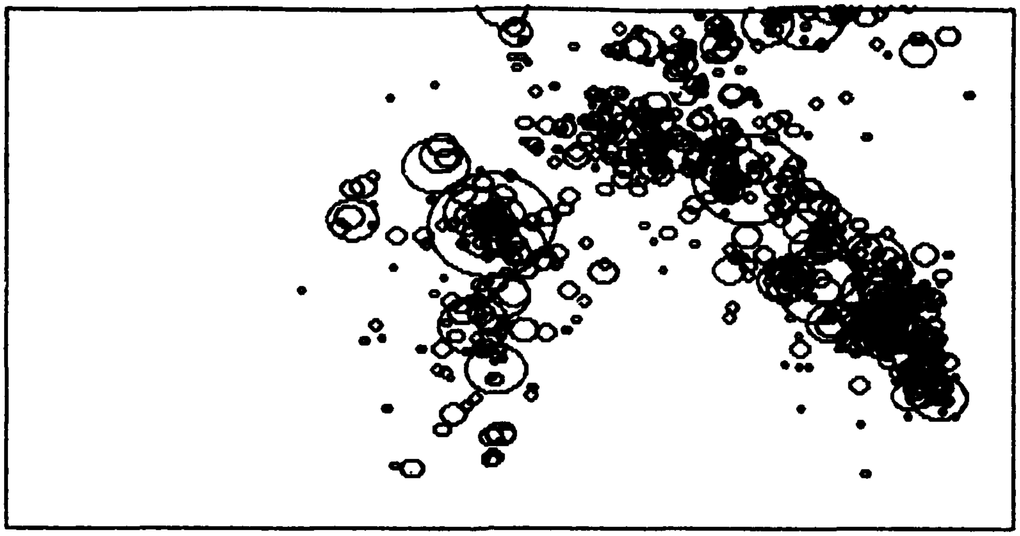


PARTICIPANT 10 RUN 43, 25-30 MINS H LOAD 1/10/91

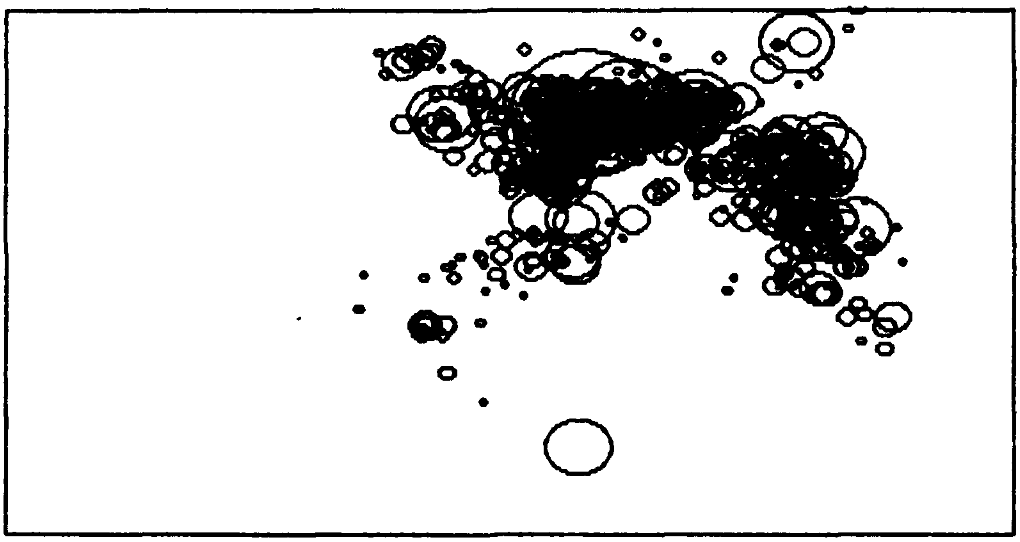


SCAN PLOTS
FULL PERFORMANCE LEVEL CONTROLLERS

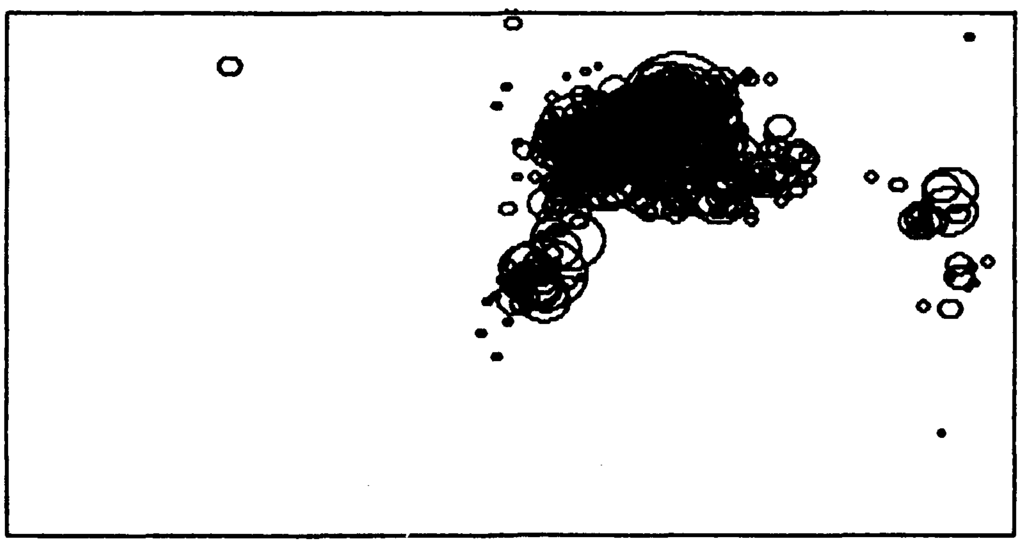
PARTICIPANT 02 RUN 2R, 0-5 MINS L LOAD 9/7/90



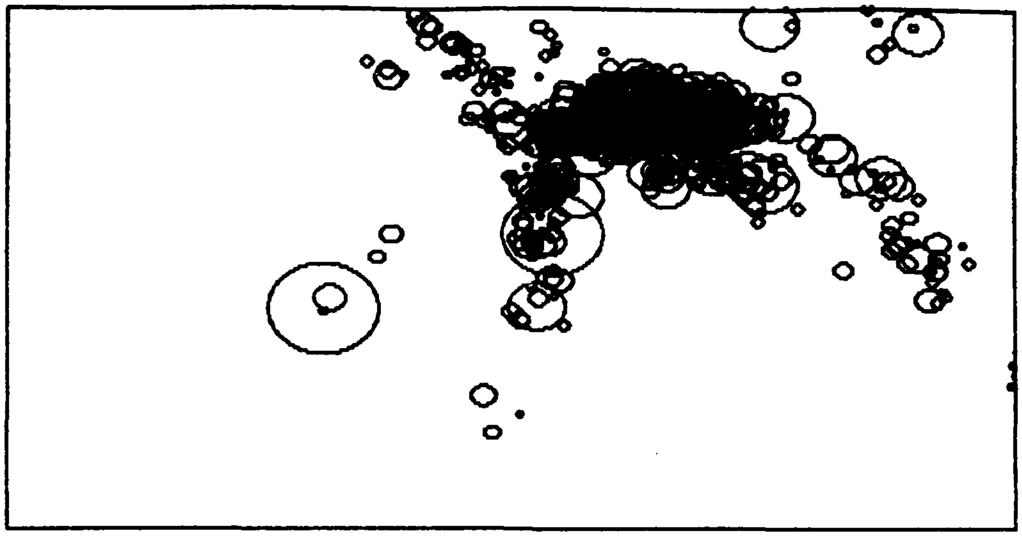
PARTICIPANT 02 RUN 2R, 5-10 MINS L LOAD 9/7/90



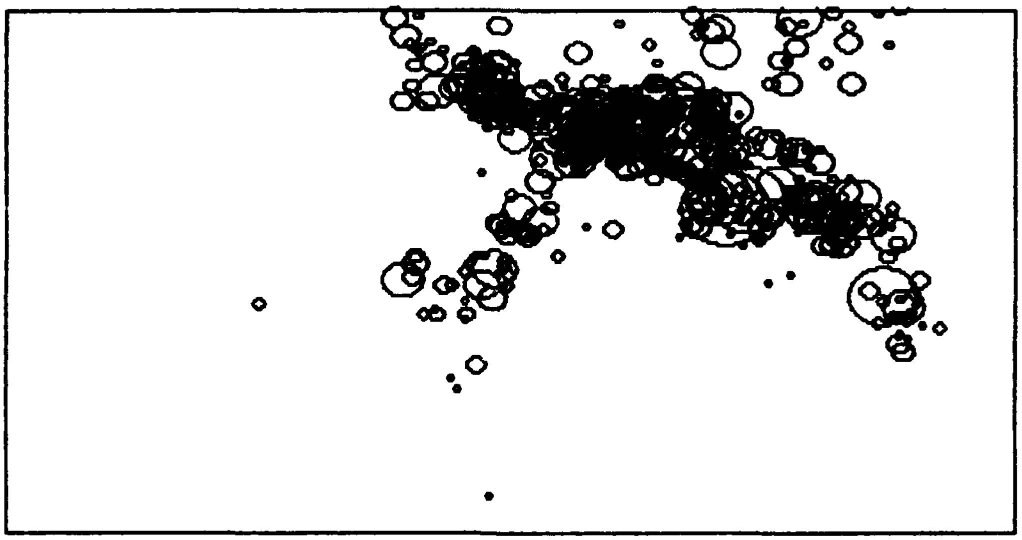
PARTICIPANT 02 RUN 2R, 10-15 MINS L LOAD 9/7/90



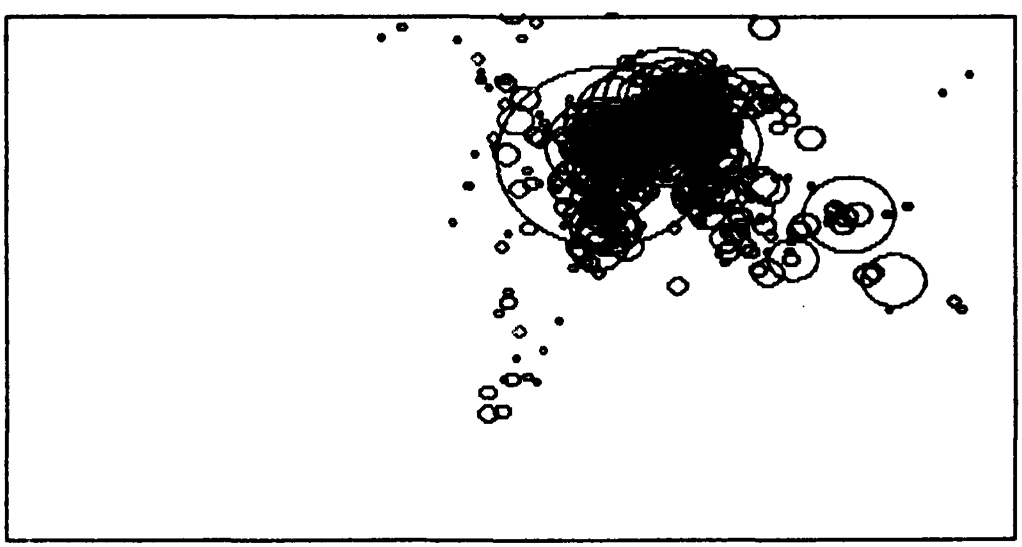
PARTICIPANT 02 RUN 2R, 15-20 MINS L LOAD 9/7/90



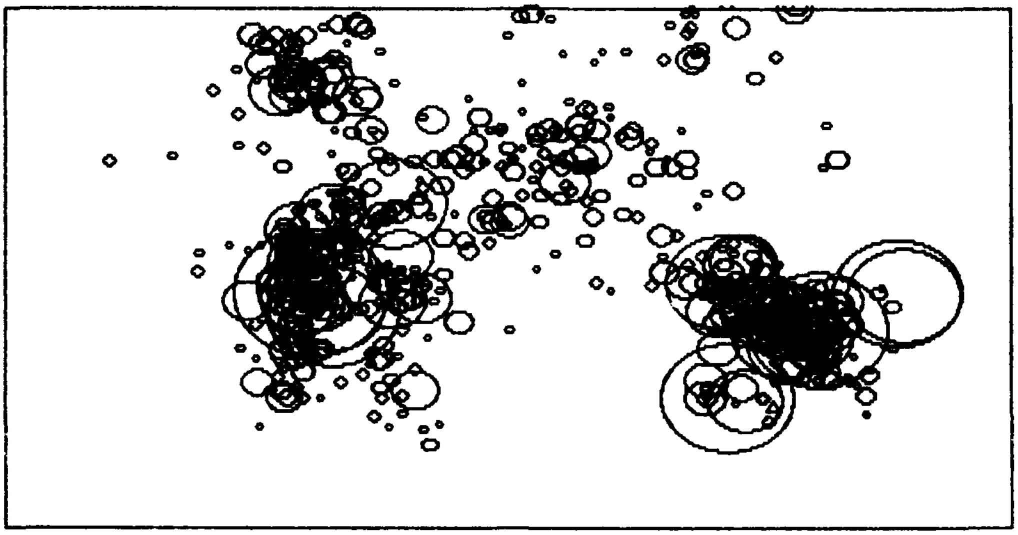
PARTICIPANT 02 RUN 2R, 20-25 MINS L LOAD 9/7/90



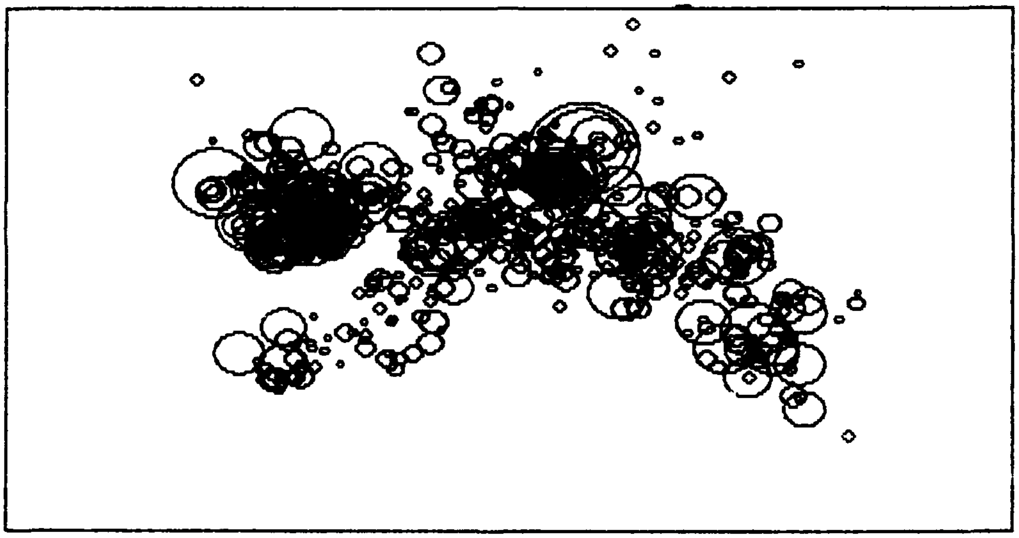
PARTICIPANT 02 RUN 2R, 25-30 MINS L LOAD 9/7/90



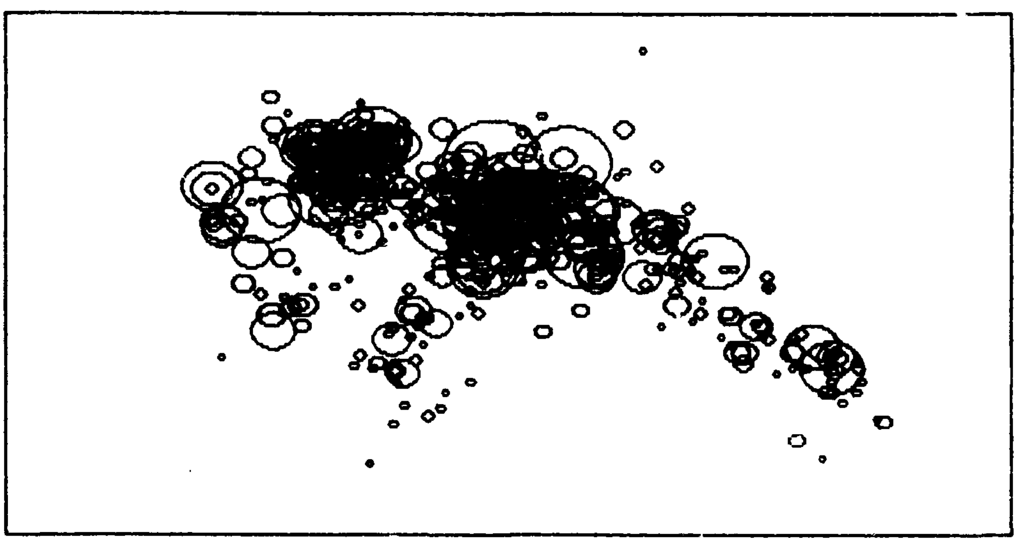
PARTICIPANT 02 RUN 03, 0-5 MINS H LOAD 9/6/90



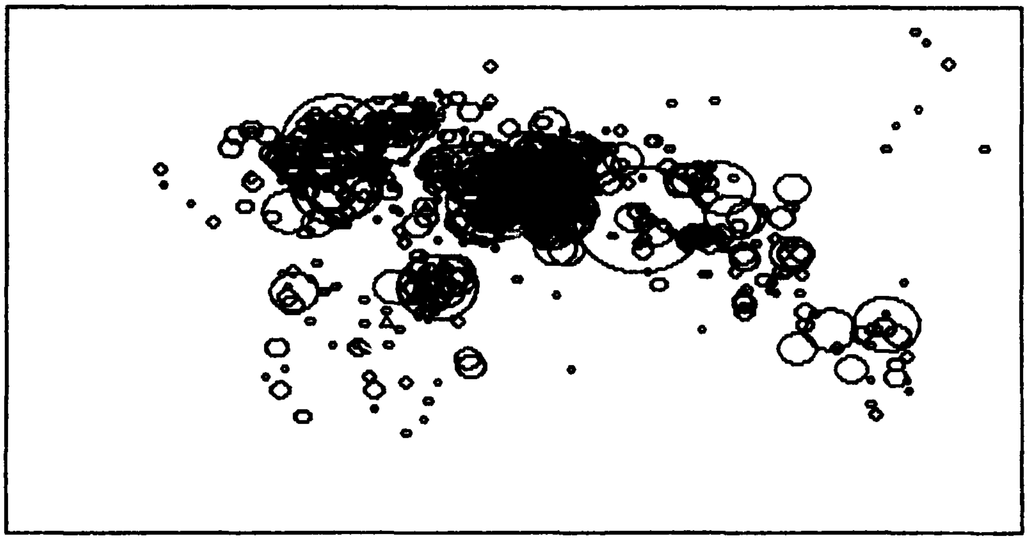
PARTICIPANT 02 RUN 03, 5-10 MINS H LOAD 9/6/90



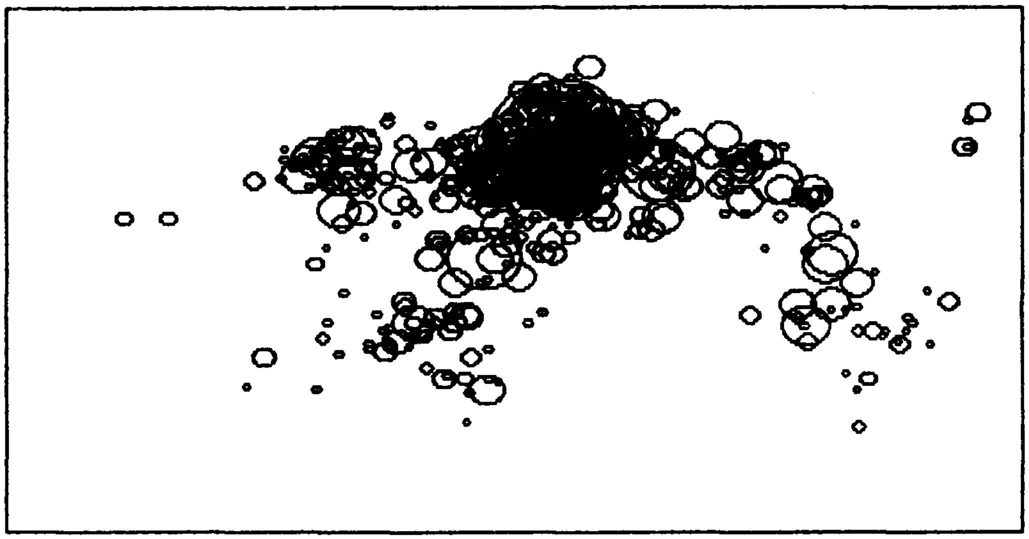
PARTICIPANT 02 RUN 03, 10-15 MINS H LOAD 9/6/90



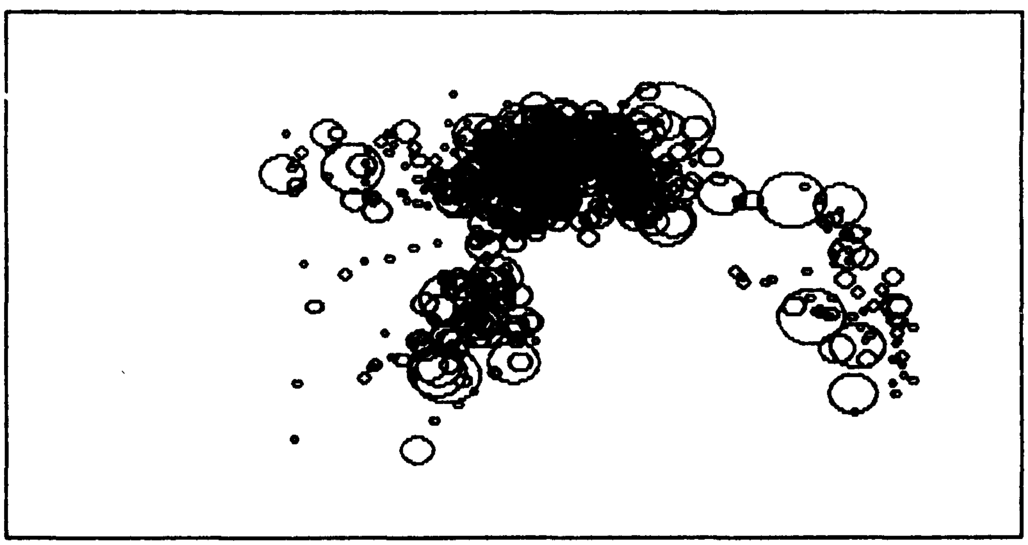
RTICIPANT 02 RUN 03, 15-20 MINS H LOAD 9/6/90



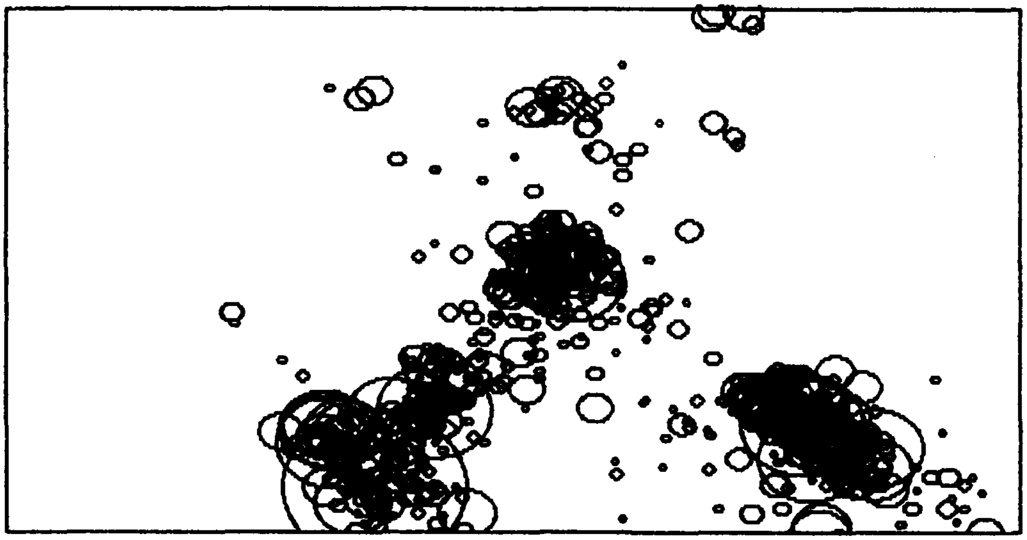
RTICIPANT 02 RUN 03, 20-25 MINS H LOAD 9/6/90



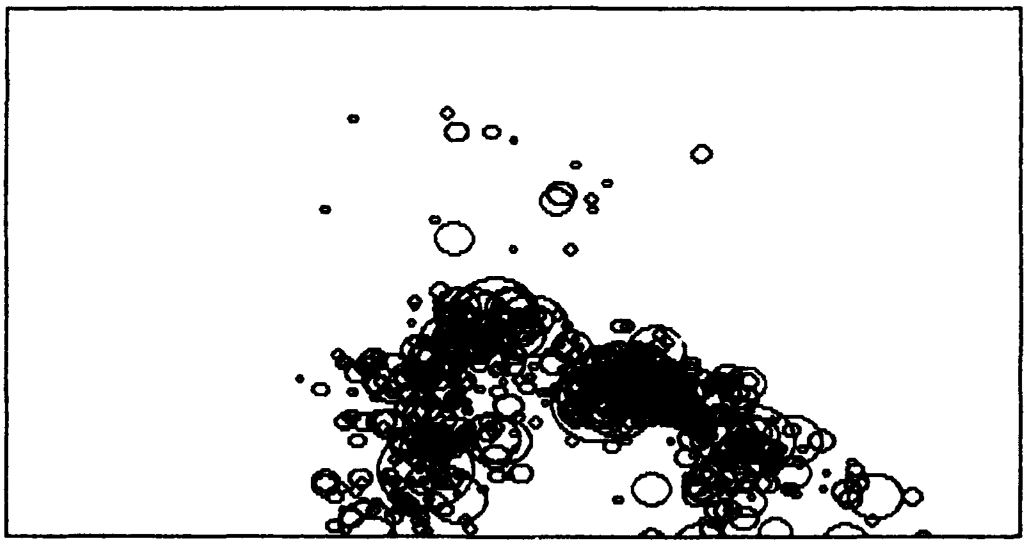
RTICIPANT 02 RUN 03, 25-30 MINS H LOAD 9/6/90



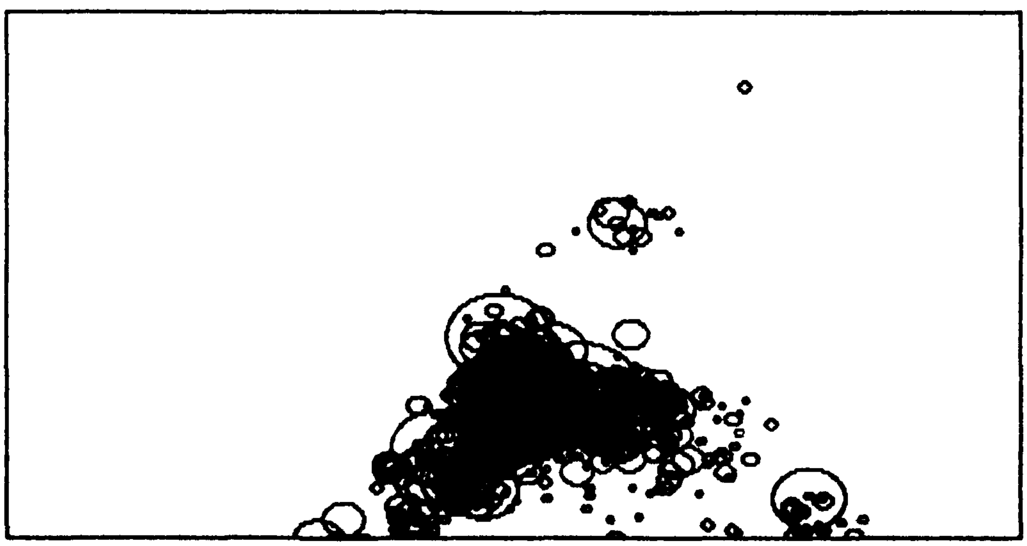
PARTICIPANT 04 RUN 11, 0-5 MINS L LOAD 9/11/90



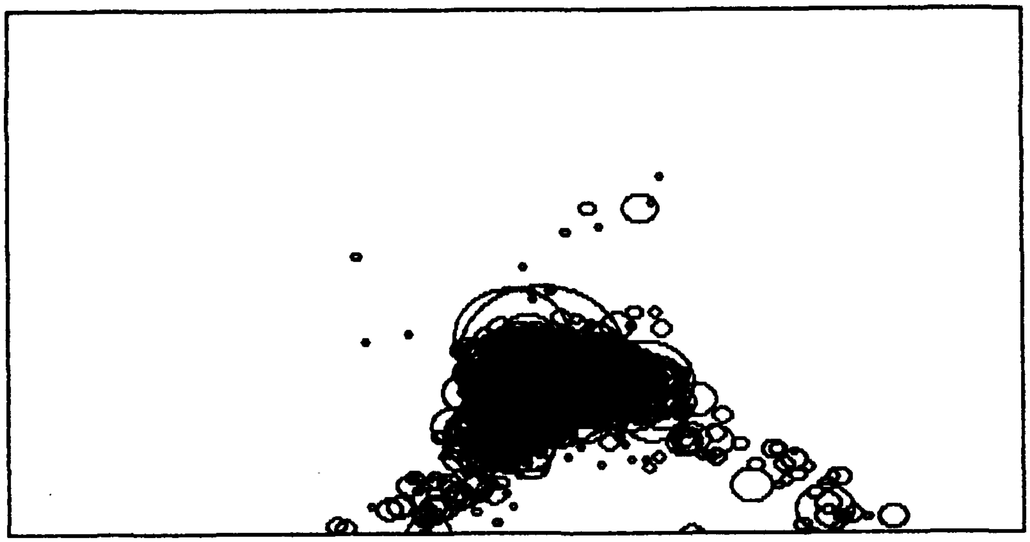
PARTICIPANT 04 RUN 11, 5-10 MINS L LOAD 9/11/90



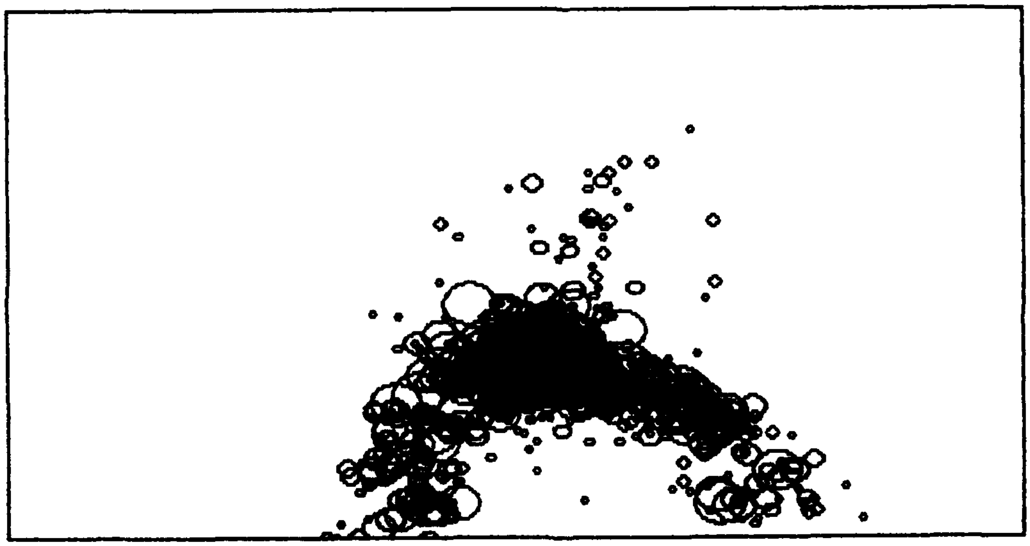
PARTICIPANT 04 RUN 11, 10-15 MINS L LOAD 9/11/90



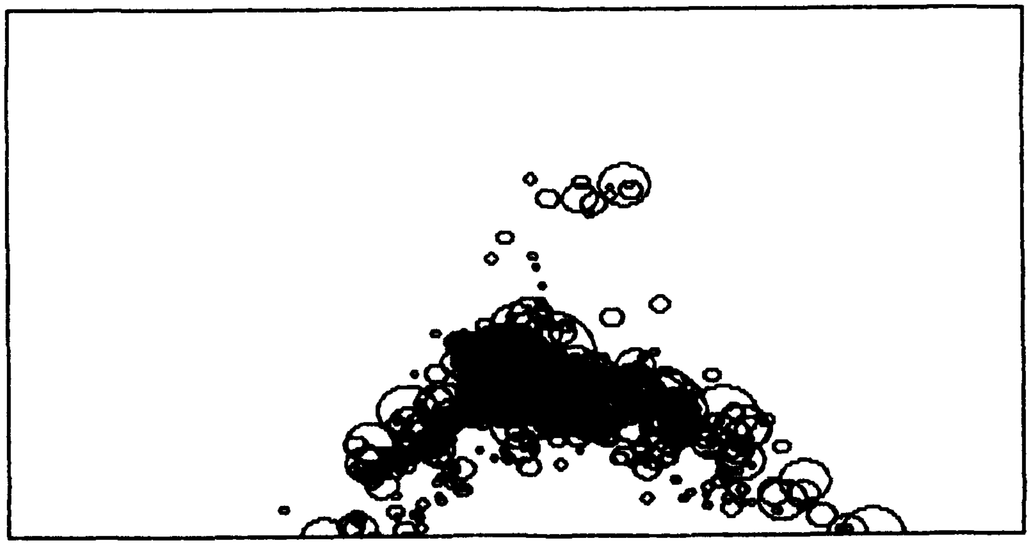
ARTICIPANT 04 RUN 11, 15-20 MINS L LOAD 9/11/90



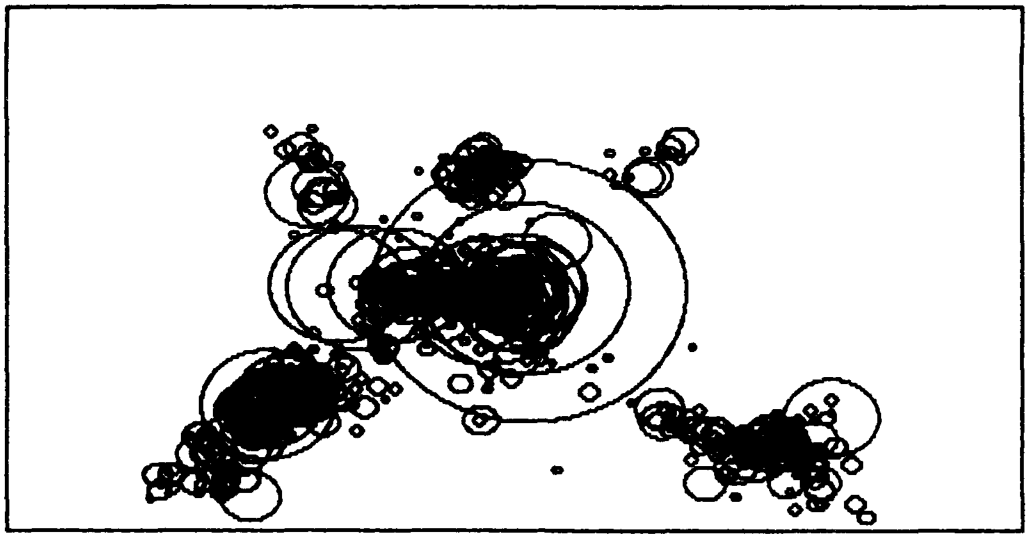
ARTICIPANT 04 RUN 11, 20-25 MINS L LOAD 9/11/90



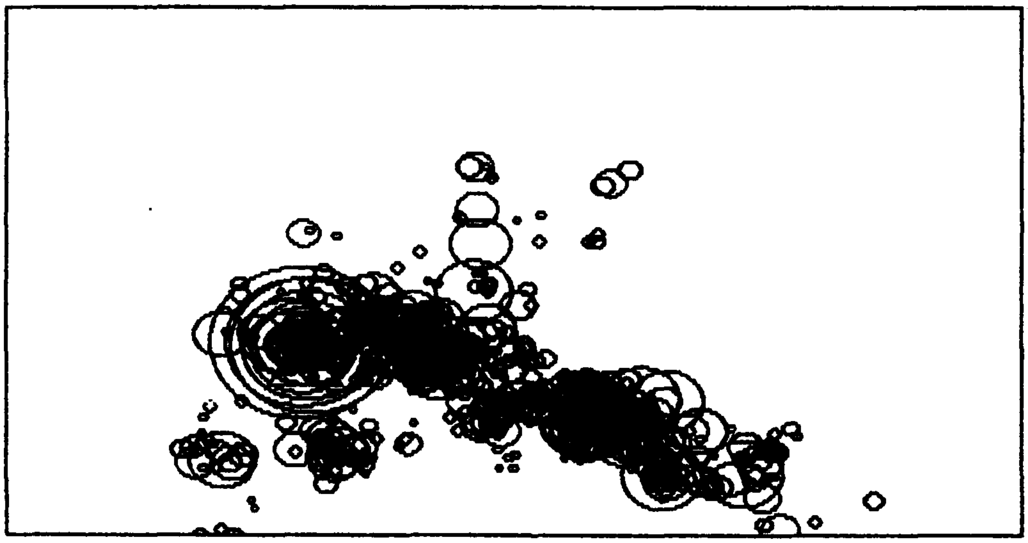
ARTICIPANT 04 RUN 11, 25-30 MINS L LOAD 9/11/90



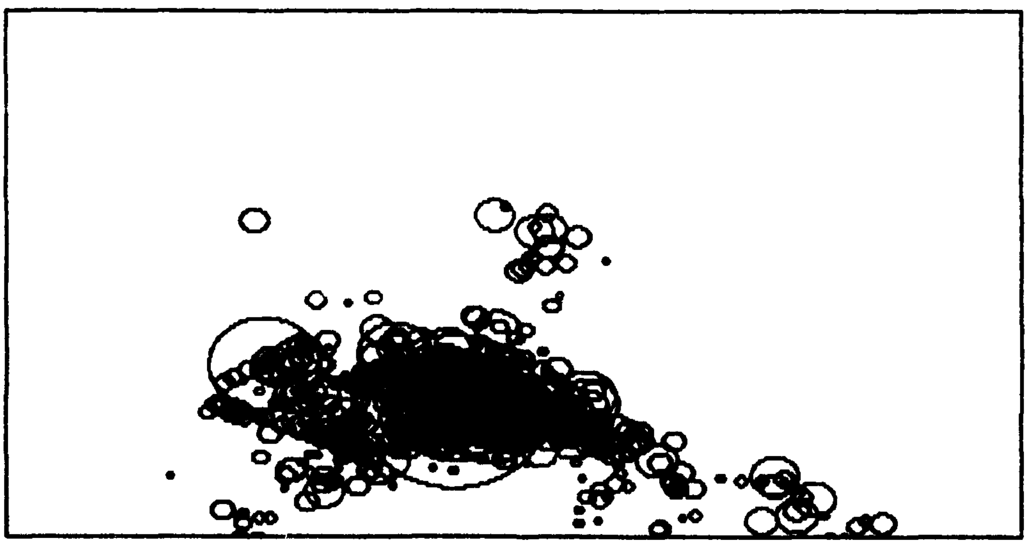
PARTICIPANT 04 RUN 14, 0-5 MINS H LOAD 9/12/90



PARTICIPANT 04 RUN 14, 5-10 MINS H LOAD 9/12/90



PARTICIPANT 04 RUN 14, 10-15 MINS H LOAD 9/12/90



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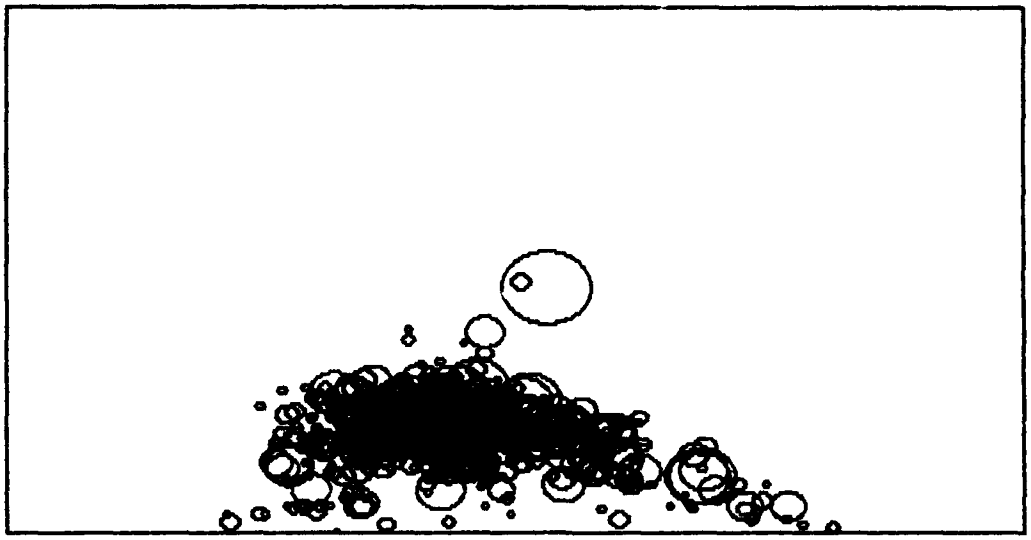

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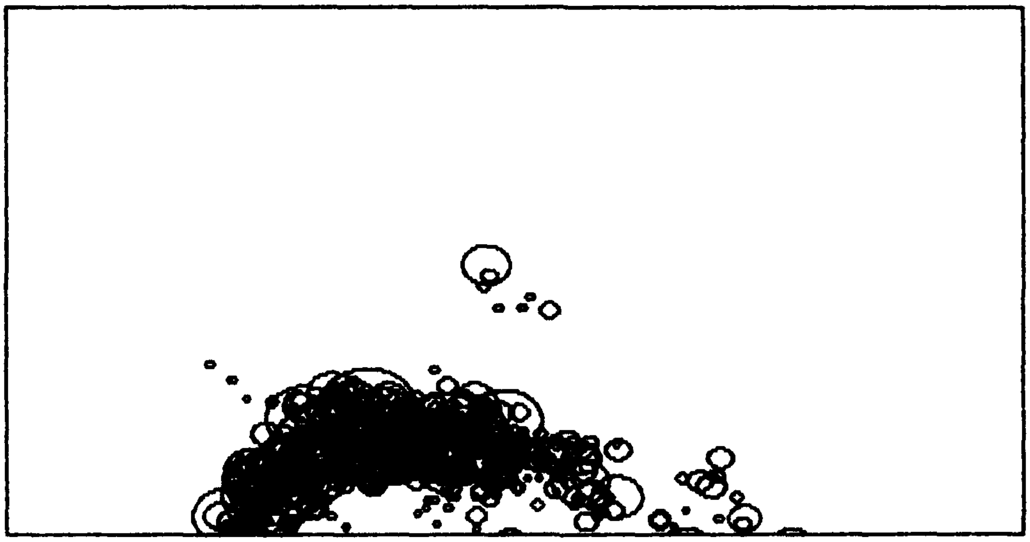

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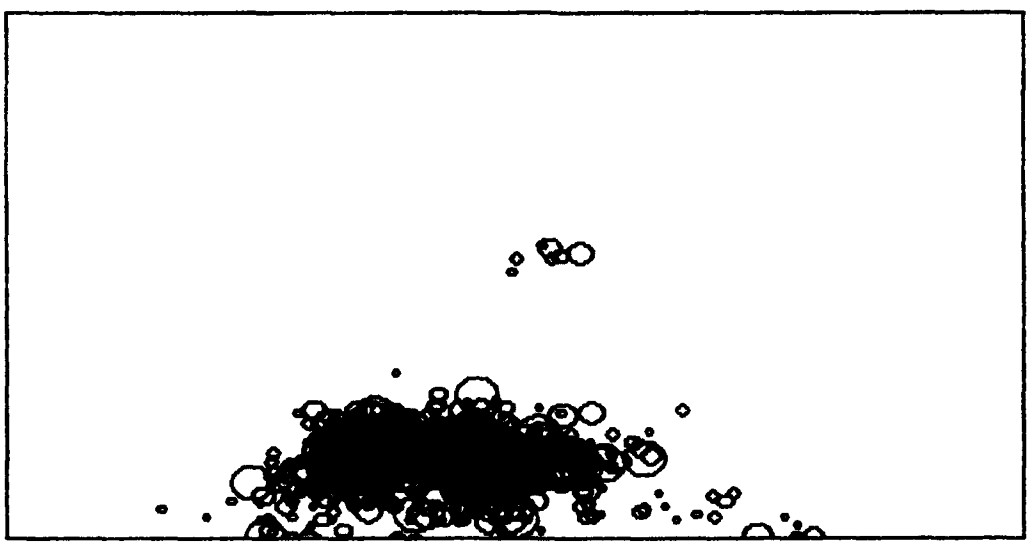

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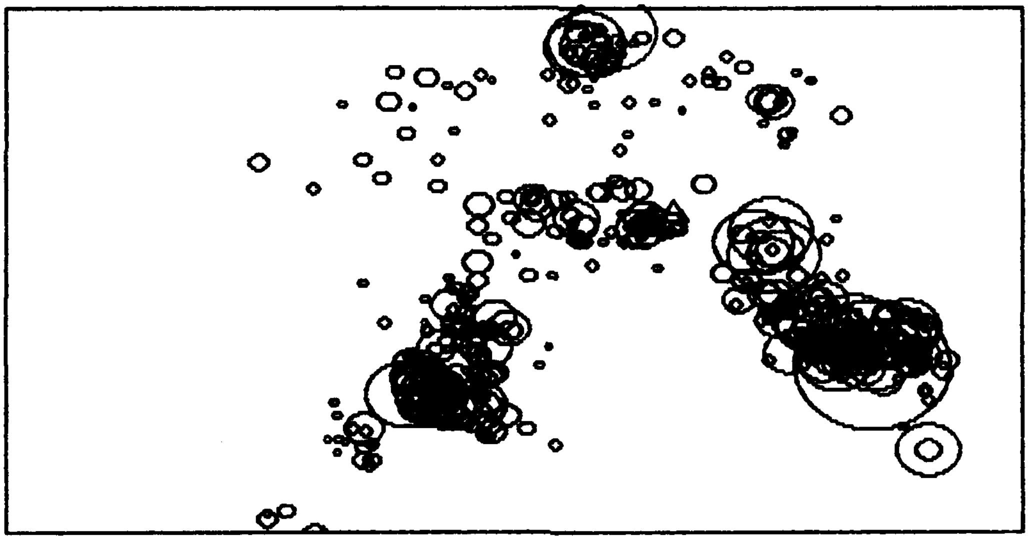

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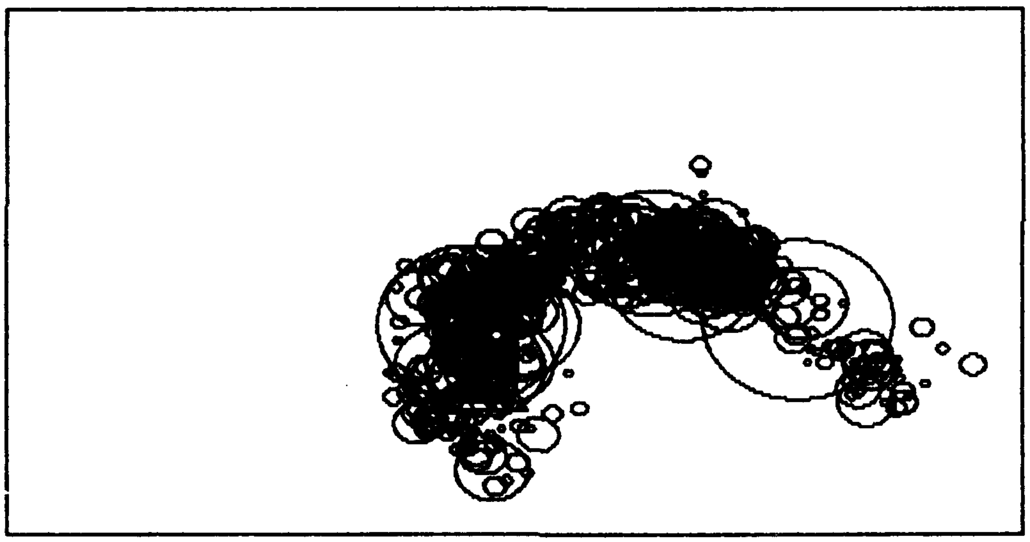

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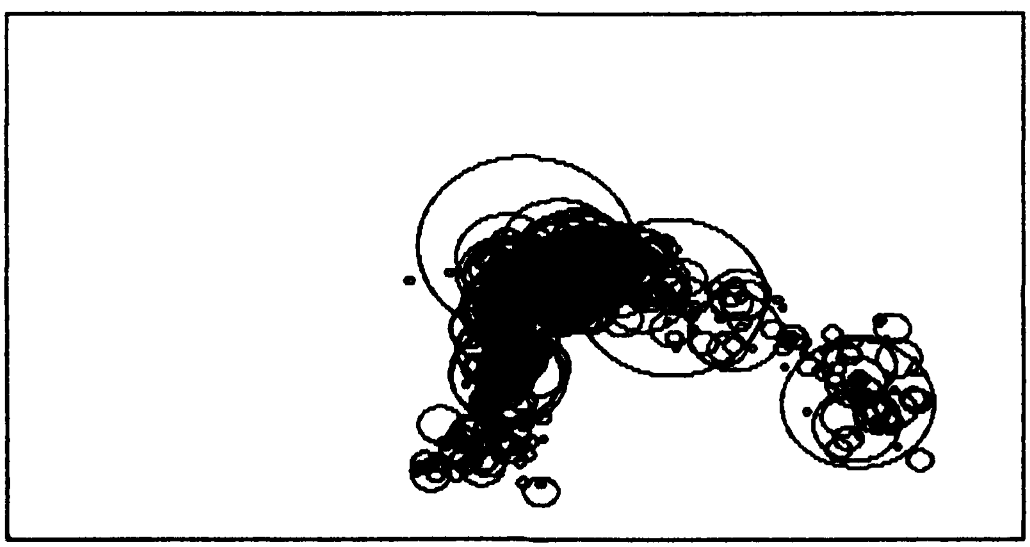

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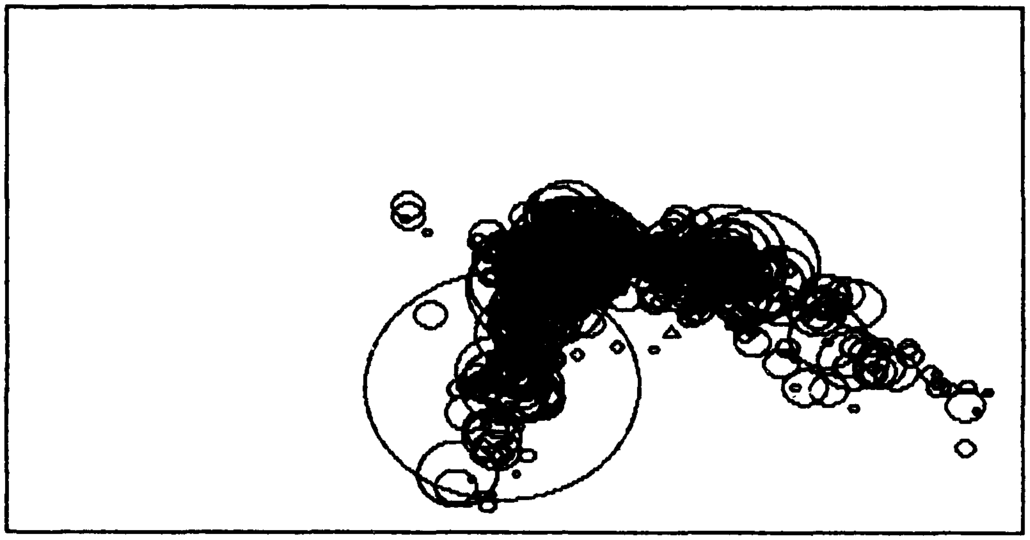

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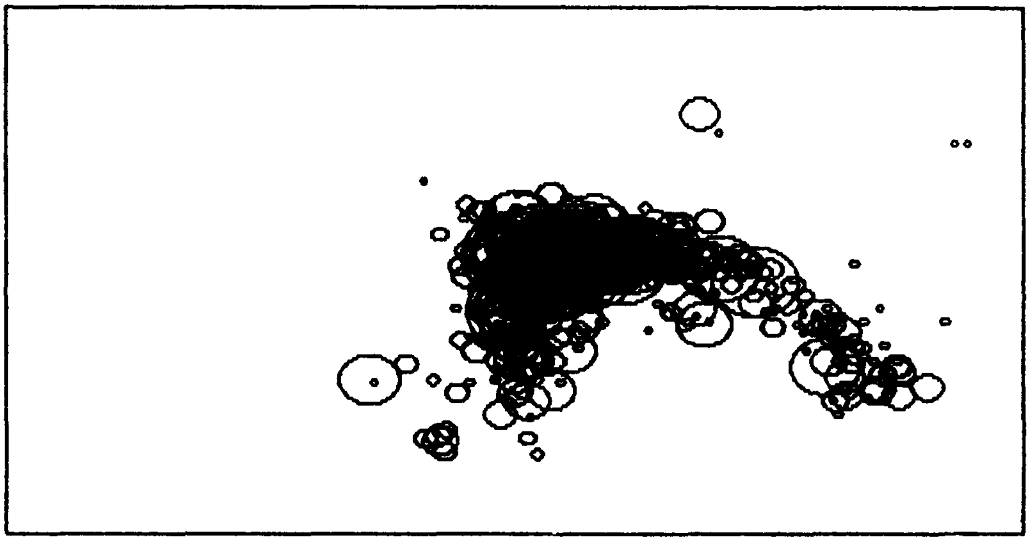

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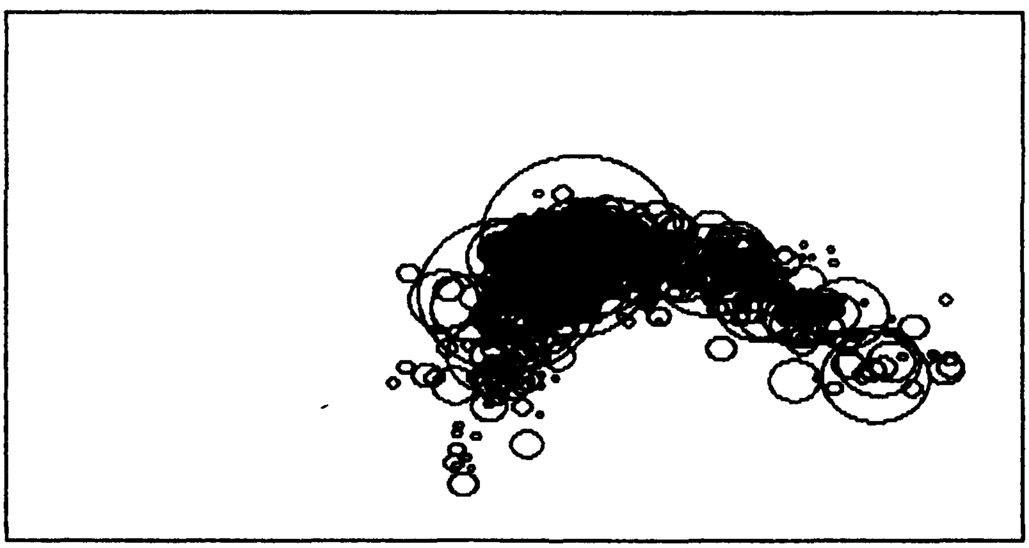

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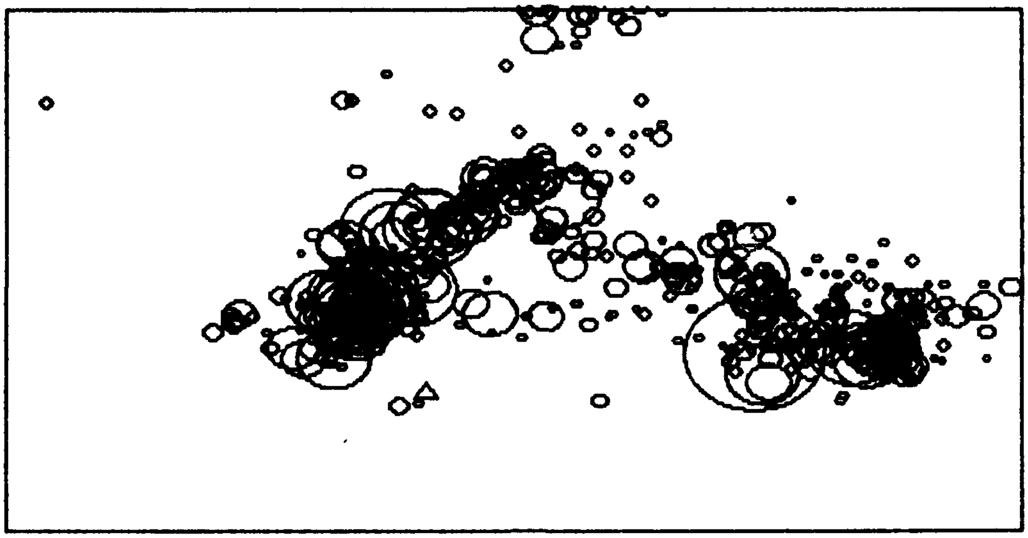

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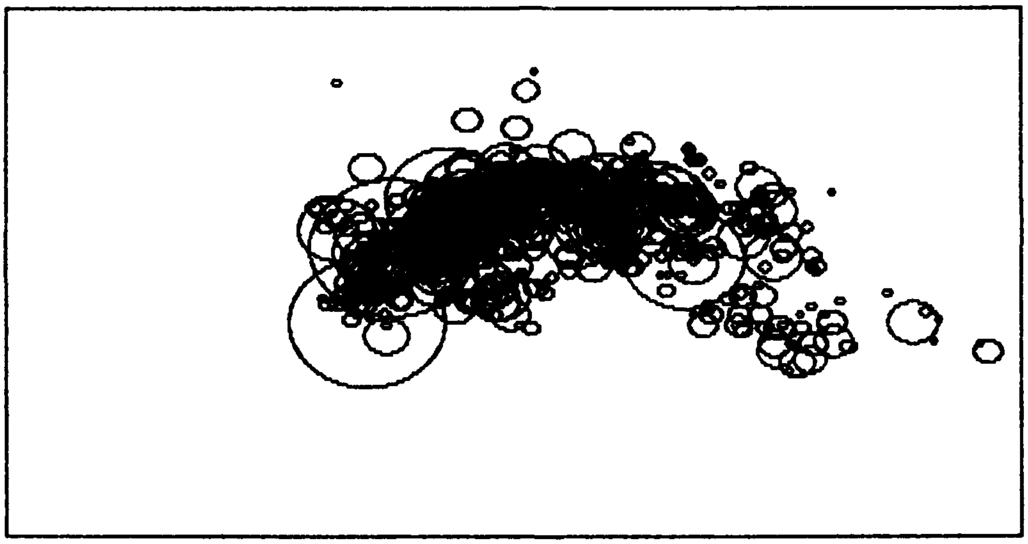

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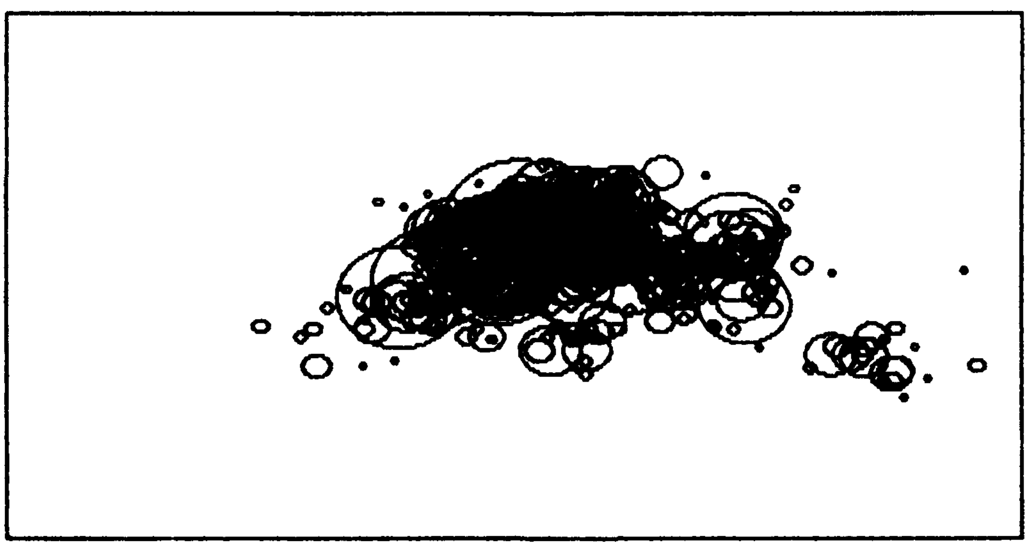

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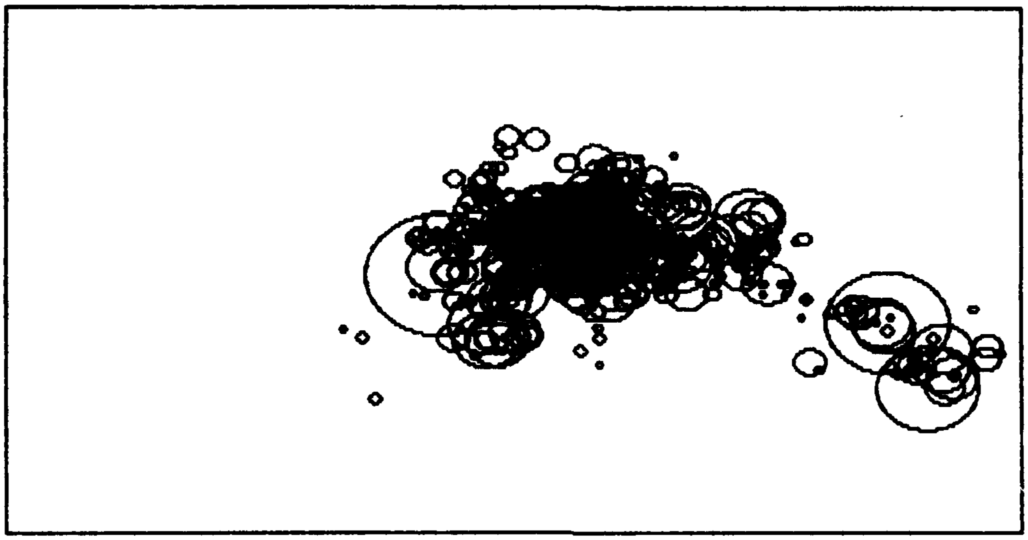

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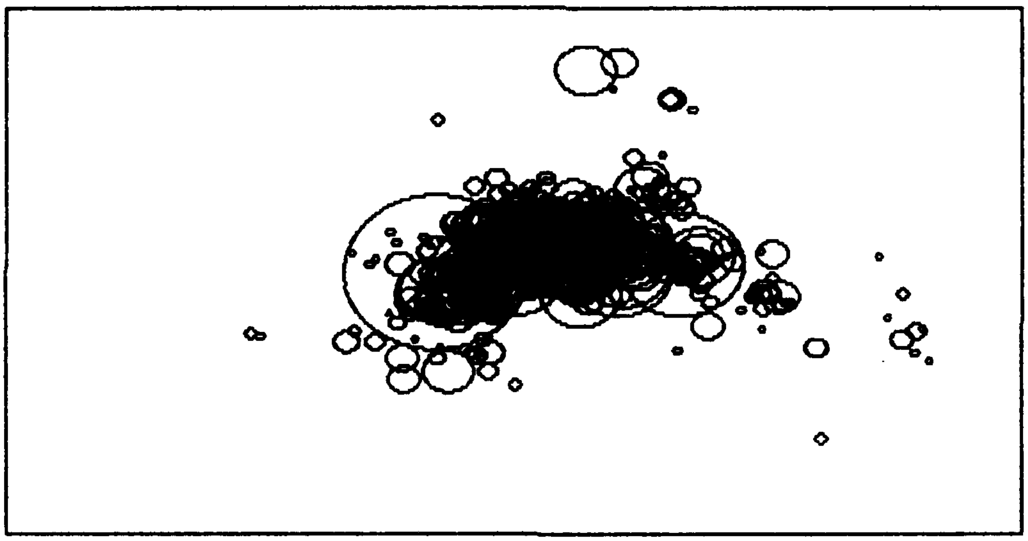

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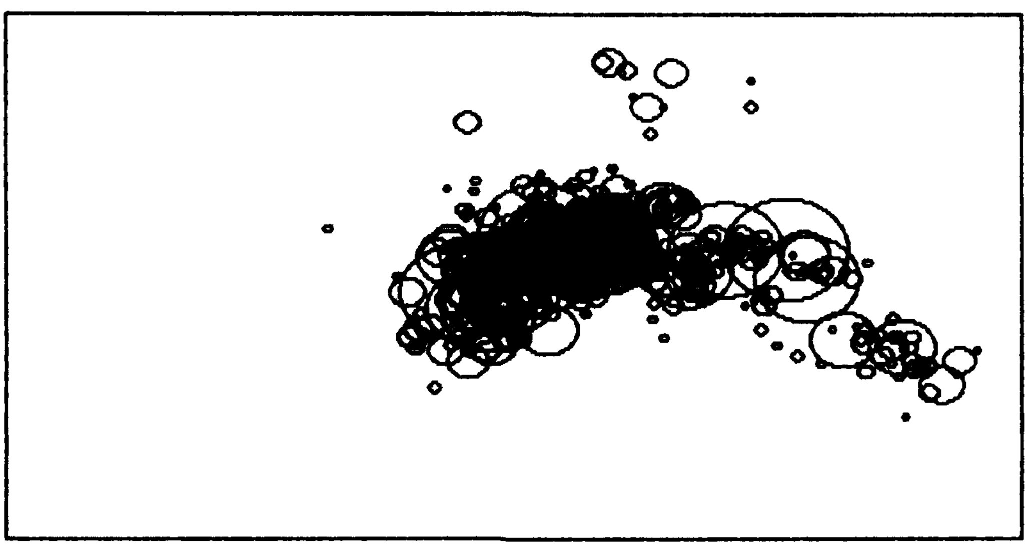

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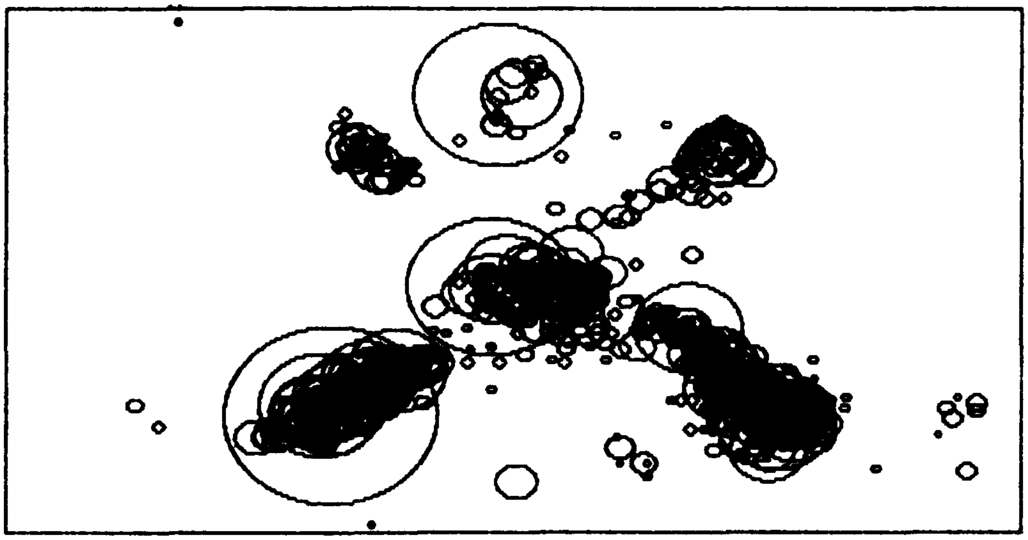

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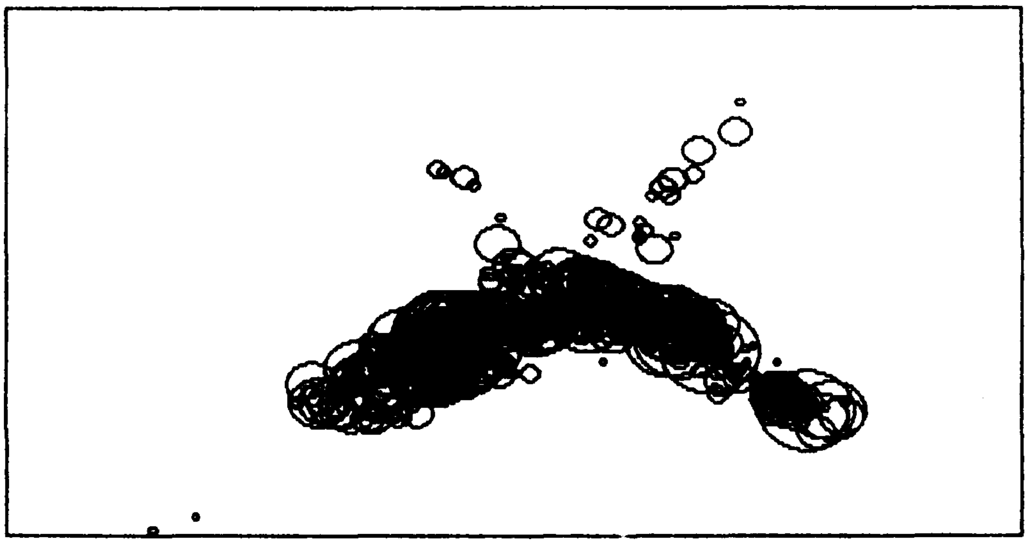

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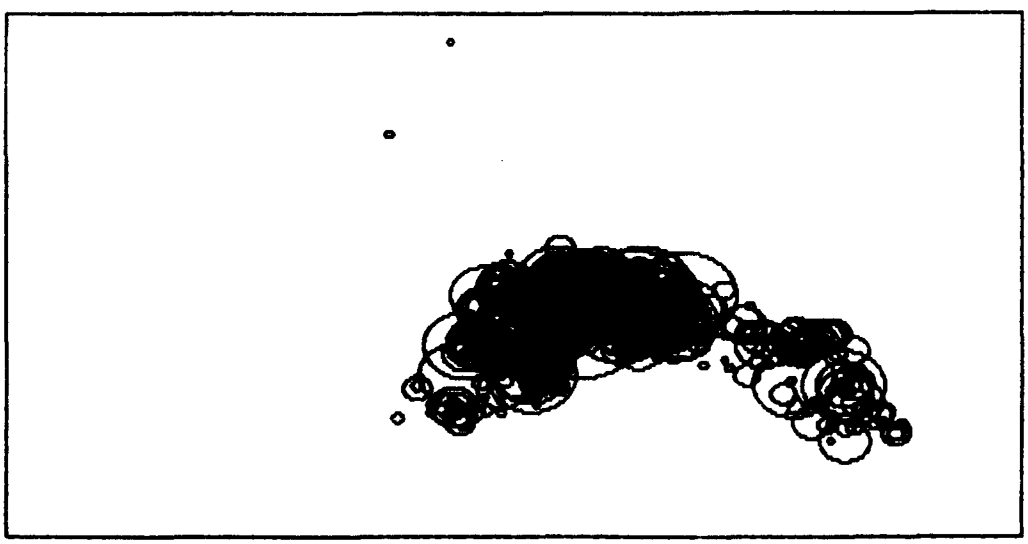

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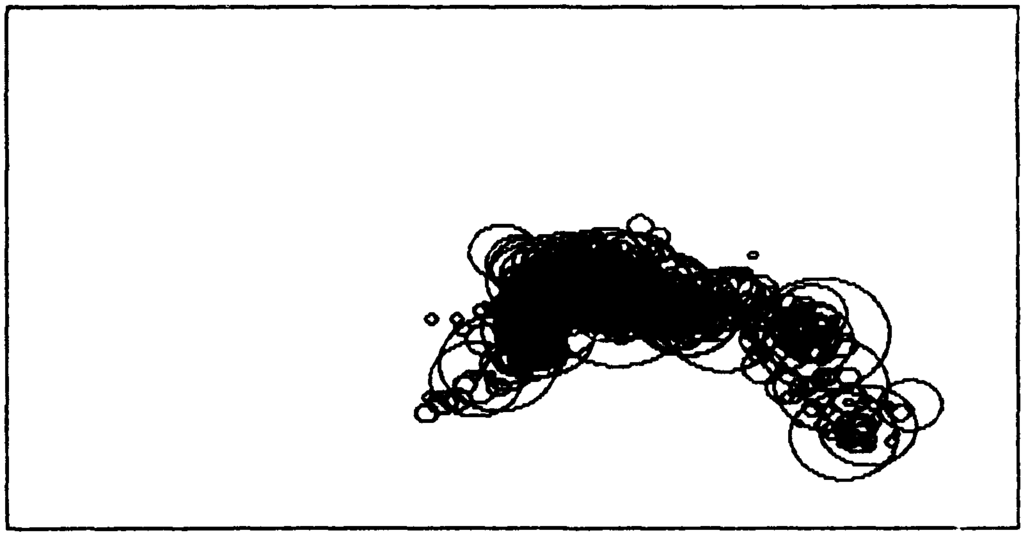

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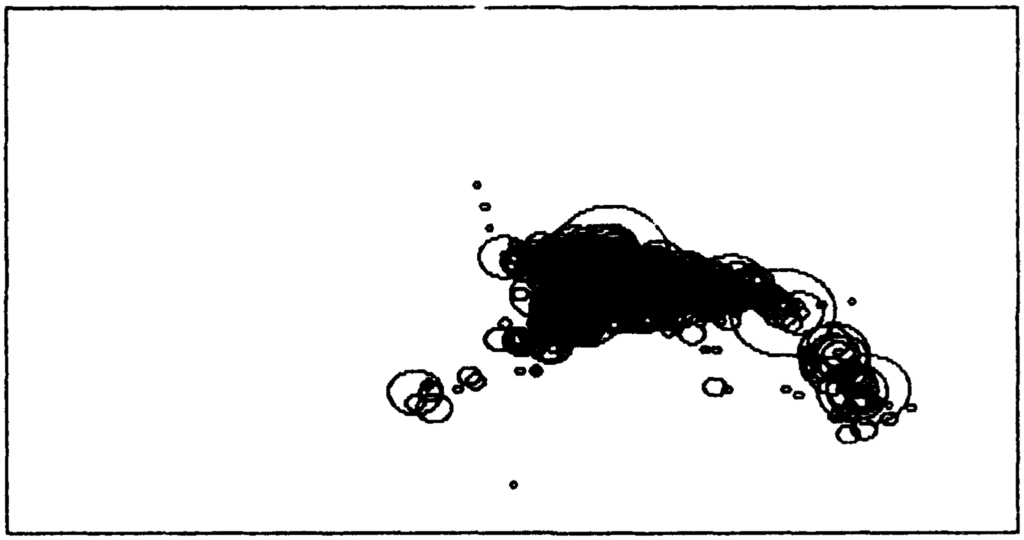

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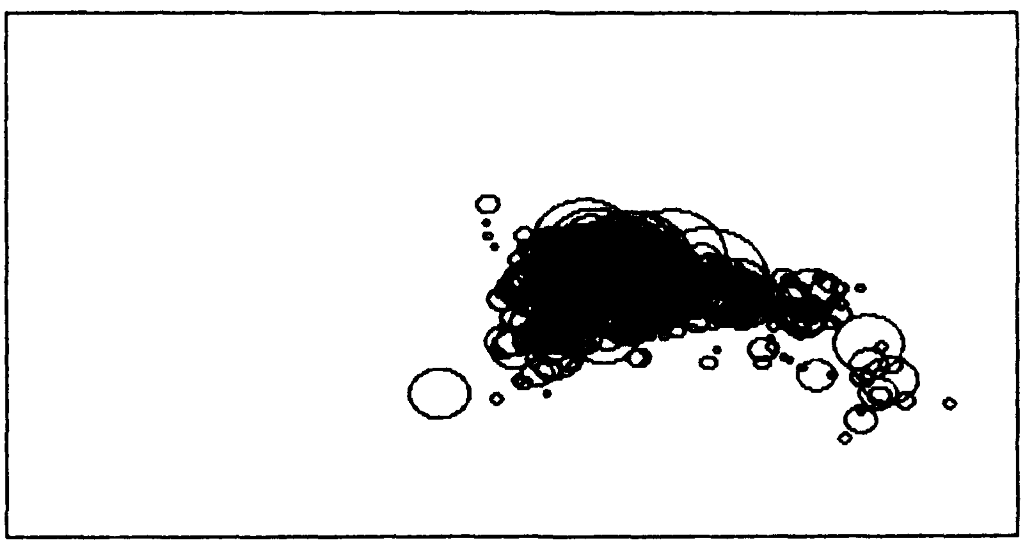

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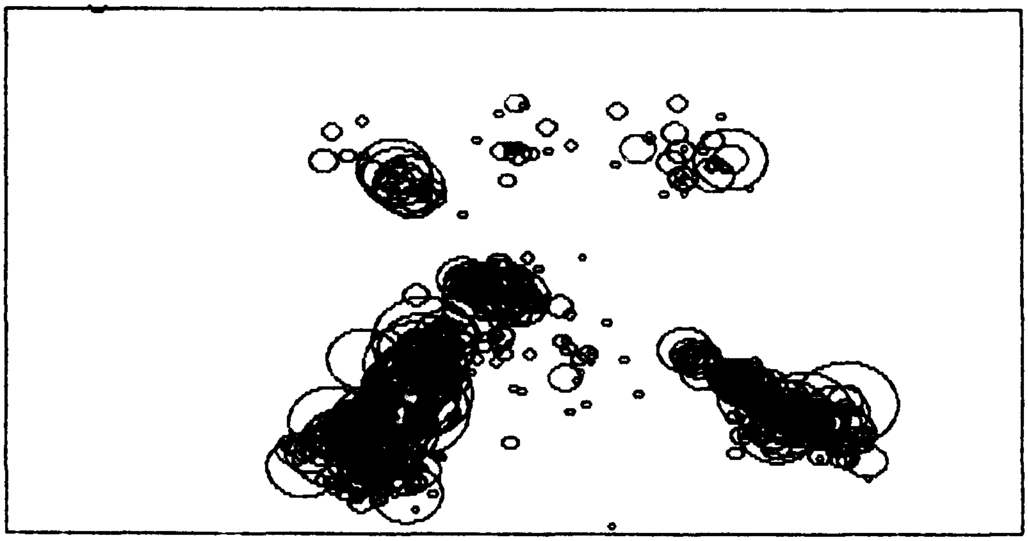

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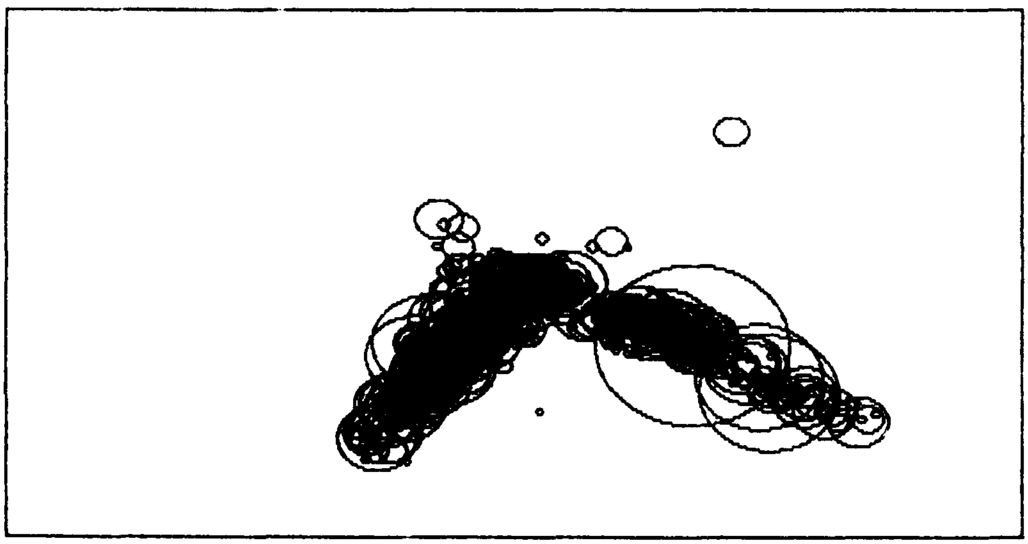

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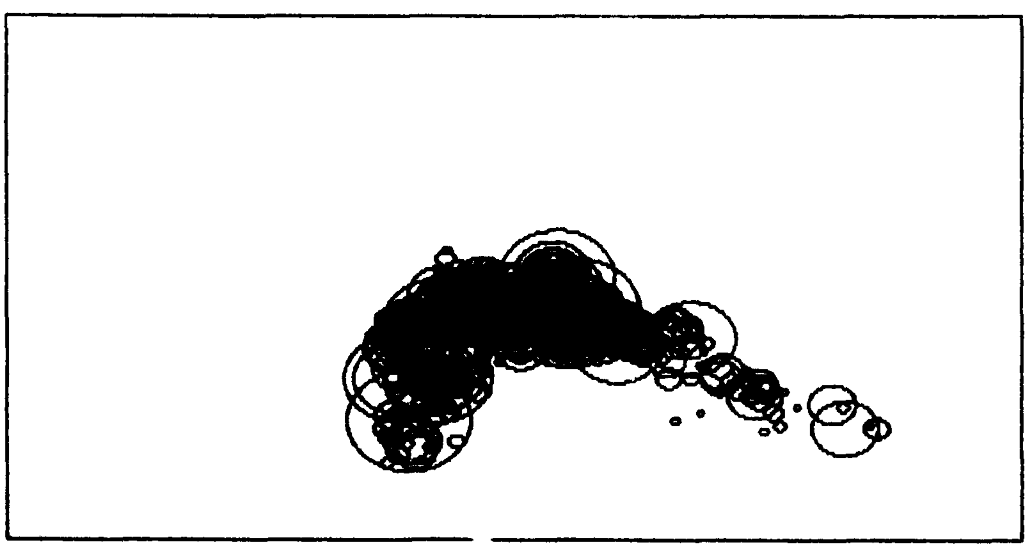

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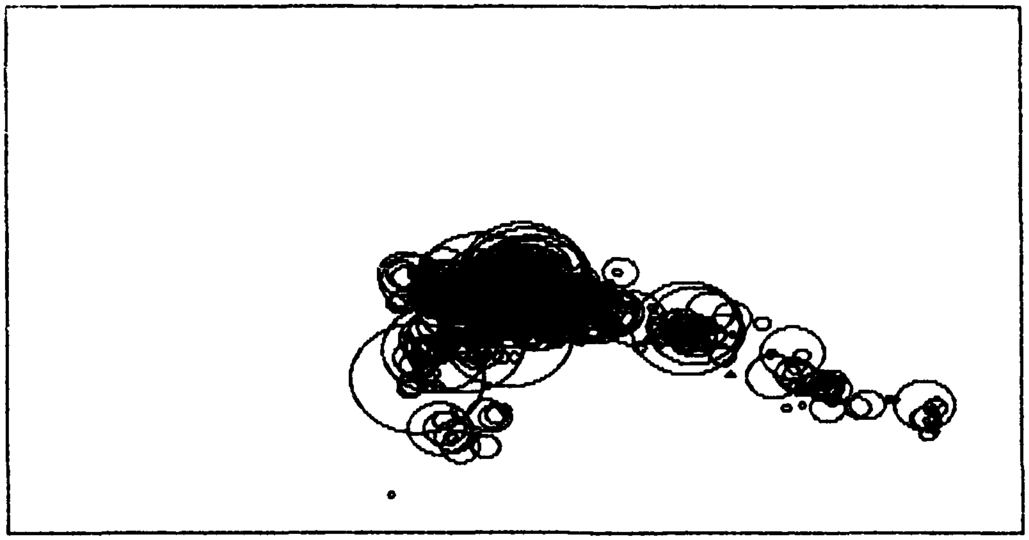

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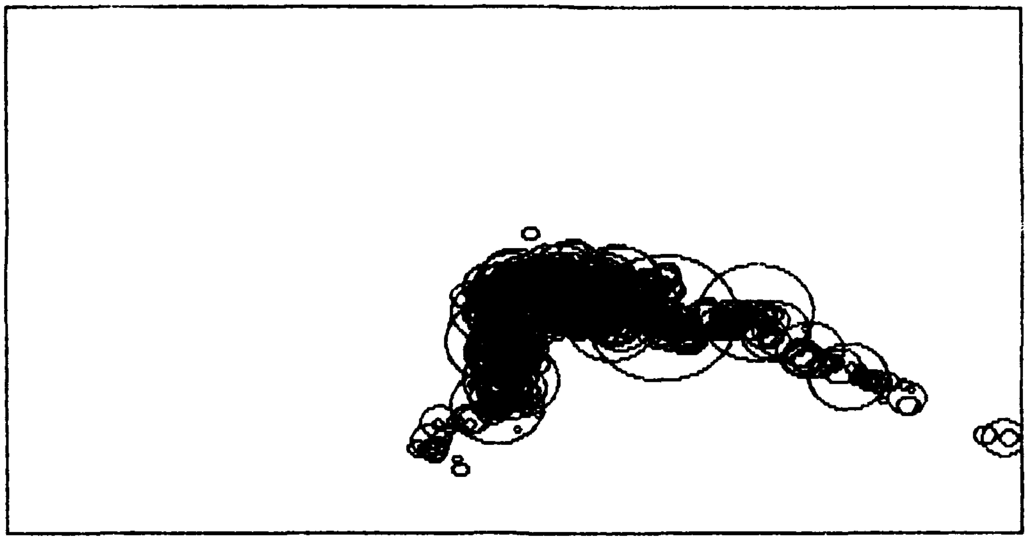

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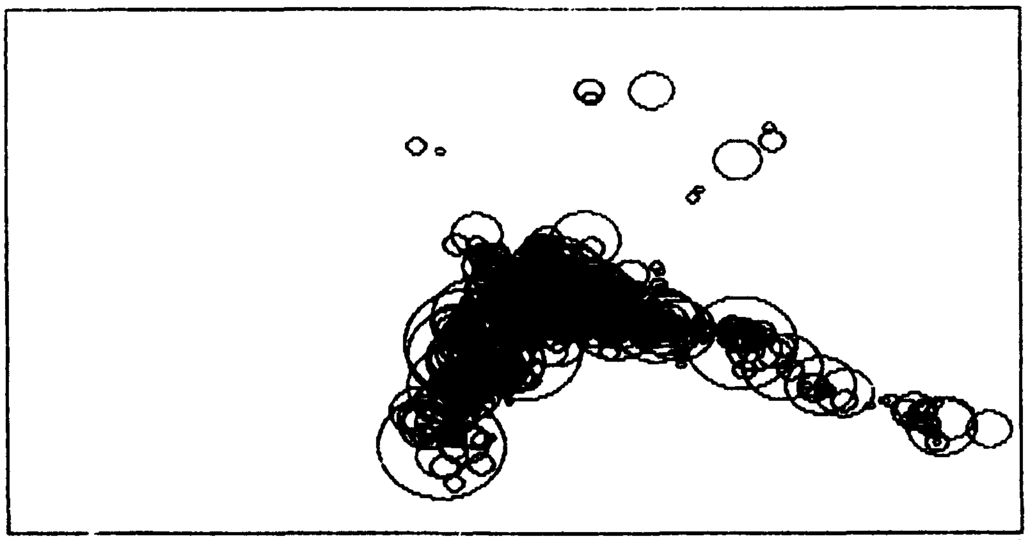

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